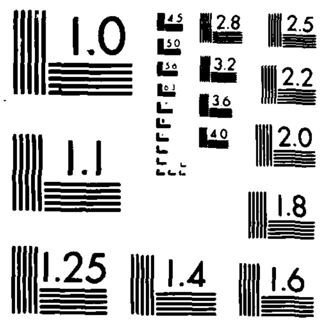
AD-A174 502 TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG AP..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. J E BOTKIN 1/2

UNCLASSIFIED SEP 86 AFIT/GSM/LSQ/86S-3 F/G 5/1 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

2

TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG APPROVED COST ELEMENT STRUCTURE

THESIS

James E. Botkin
Captain, USAF

AFIT/GSM/LSQ/86S-3

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSQ/86S-3

TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG APPROVED COST ELEMENT STRUCTURE

THESIS

James E. Botkin
Captain, USAF

AFIT/GSM/LSQ/86S-3

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GSM/LSQ/86S-3

TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG APPROVED COST ELEMENT STRUCTURE

THESIS

Presented to the Faculty of the School of
Systems and Logistics of the Air Force
Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

James E. Botkin, B.S.
Captain, USAF

September 1986

Approved for public release; distribution unlimited

Preface

The purpose of this study was to modify the present LCC-2 life cycle cost cost element structure to reflect the office of Secretary of Defense Cost Analysis Improvement Group (OSD/CAIG) guidance concerning standardization of aircraft systems cost elements.

The LCC-2 model was used prior to the CAIG's standardization effort and was considered an effective life cycle cost model for avionics systems destined for implementation on one individual type of aircraft. However, with the CAIG's decree for standardization of cost element structures to achieve comparability between differing systems life cycle costs, the LCC-2 model's use suffered due to non compliance with the standard. By modifying the cost element structure of the model to yield compliance with the CAIG standard aircraft cost element structure the model will again be a useful tool for the life cycle cost analyst of avionics systems.

My appreciation and deep thanks to my advisor, Lt Col John Long for his undying support, guidance and understanding through many trials and temporary disappointments. Also my thanks to my reader, Mr. Roland Kankey, for his exceptional review of the thesis from beginning to end and his many insightful and knowledgeable comments. I would also like to thank Mr. Dan Ferens for his advice and assistance concerning the difficult area of software maintenance life cycle costs.

Thank you Kathy, Jimmy, and Laura for being patient and as understanding as possible for the long hours I've missed with you all. I promise to carefully consider the past before embarking on such a trying academic effort again.

James E. Botkin

Table of Contents

List of Tables

Abstract

This modification of the LCC-2 life cycle cost model cost element structure has separated acquisition costs from O&S costs, and by then adding missing ownership cost elements, has transformed the model into compliance with the Secretary of Defense Cost Analysis Improvement Group's (OSD/CAIG) standard cost element structure for aircraft systems. The modification of the software code to implement the modified cost element structure will once again allow the extensive use of the model for life cycle cost analysis.

The modification was accomplished through a comparison of the LCC-2 cost elements with the CAIG approved cost elements and modifying the LCC-2 cost estimating relationships, which produce the cost elements, so as to generate the approved cost elements. Additionally, new cost estimating relationships were devised to supply output for cost elements not previously addressed by the LCC-2 model.

Although the model was originally developed for use in the life cycle costing of avionics systems, the model should be applicable to other aircraft subsystems as well.

TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG APPROVED COST ELEMENT STRUCTURE

I. Introduction

General Issue

The DOD began realizing in the mid 60's that the operating and support (O&S) costs, as a percentage of the DOD budget, were rapidly increasing (33:1). This rapid increase in O&S costs prompted the deputy Secretary of Defense, W.P. Clements Jr., to issue MBO 9-2.

The guidance tasked the military departments to
(1) develop weapons systems operating and support cost visibility,
(2) develop component level cost visibility,
(3) standardize O&S cost terminology and definitions DOD-wide, and
(4) institutionalize the O&S cost systems at each service [33:2].

Until the formation of the Cost Analysis Improvement Group (CAIG) in 1973, there was no universally accepted framework for defining and accounting for the life cycle cost (LCC) of Department of Defense (DOD) weapon systems (15:Ch 1, 6). This lack of an accepted framework allowed a certain amount of latitude on the particular cost element structure (CES) used. LCC estimates had been and still are required for each major weapon system milestone decision at the Defense Systems Acquisition and Review Council (DSARC). The DSARC has recently been replaced by the Joint Requirements Management Board (JRMB). The structure is essentially unchanged, and the same milestone process is employed (20:15). The LCC estimates are produced as output from LCC models. Without an accepted framework, a problem exists with the outputs due to the arbitrary choice of a cost element structure to build the LCC model. As a result of the arbitrary foundation of the LCC estimates, problems arise in the interpretation and comparability of competing weapons system's LCC.

Under the Office of the Secretary of Defense (OSD), one of CAIG's functions was to standardize the cost element structure for DOD LCC estimates (11:2). Concerning aircraft, "the OSD (CAIG) has published three superseding sets of cost structures: a guide in May 1974, an updating memorandum in August 1977, and an updated guide in April 1980" (29:Ch 4, 1). The standardization of the LCC cost element structure DOD-wide would aid in the improved understanding and the accurate and rapid comparison of alternative weapons system's costs. This would lead to better utilization of DOD funds and the acquisition of efficient and effective weapons systems.

One of the benefits from utilizing LCC as a decision tool will be cost savings which may then be channeled into the procurement of weapons systems to meet the threats of the future. LCC consists of all the cost to develop, acquire, operate and support, and dispose of a system. The (O&S) portion of a system's cost steadily increased in the mid 60's. In the past six years this percentage has generally been dropping from approximately 57% to 52%, with the exception of 1985 which was 57% (39). During the mid 60's and early 70's, O&S costs were at such a high level that they threatened to absorb the majority of all the future funds in the DOD budgets and crowd out the procurement of new weapons systems that would be needed to counter unknown future threats. This was caused by the pressure for increased performance and schedule constraints and lack of a LCC approach back in the early 60's. More recently the lag in the implementation of LCC management and the long O&S life of major weapons systems (eg. B-52) have resulted in continuing problems. Currently, the DOD is paying for past decisions. If the LCC approach had been adopted earlier and effectively implemented, the current O&S budget would be lower, which would free funds, both now and in the future, for the development, acquisition, support and disposal of systems to counter future threats. In addition, the better producible and supportable design which lowered cost would also increase maintainability, supportability, and mission effectiveness.

Powers and Recktenwalt (32) believe that the need for a LCC approach evolved due to O&S cost growth in an increasingly high technology environment. They attribute the rapidly changing environment to the Soviets' successfully orbiting the first satellite (SPUTNIK) in 1957. The United States viewed itself as falling behind the Soviets technologically. Powers and Recktenwalt have stated, "this threat to our national security provided the impetus for a change in our acquisition philosophy from 'fly before buy' to 'concurrency' "(32:12). This change in philosophy yielded weapons systems in shorter times, however, Powers and Recktenwalt comment, based on interviews with then Major Jack L. McChesney, that "Major defects within this philosophy are higher cost per unit and post-production solutions of designed-in-defects"(32:12-13). Powers and Recktenwalt summarize the change in philosophy by quoting Major Malcolm Bolton from his unpublished Air Command and Staff College research paper "AFSC and AFLC: An Argument for Merger" (32:13).

> The key point to remember is that with this philosophy, time is the driving mechanism- management is devoted to time reduction, and cost reduction must of necessity play a lesser role [32:13].

This philosophy was prevalent until the beginning of the 70's. In 1968 O&S costs for weapons systems exceeded 50% of the total LCC for the systems (33:1). As time passed weapons systems incorporated sophisticated new technologies resulting in greatly increased O&S costs. Strategic planners noticed that in the near future the DOD would not have the resources to support the acquired systems and develop new systems. By 1974 the DOD O&S costs had risen to

70% of the total weapons systems costs (5:2). Recently, the O&S costs, as a percentage of the DOD military budget, have been 56.9, 56.6, 55.8, 53.9, 52.1, and 57.1 percent for the years 1980 through 1985 respectively (39). (The increase for 1985 is due in part to the new policy of including retirement pay directly in the DOD budget). A management strategy employing the LCC approach has been recognized as a viable tool for controlling rising DOD costs. The economic environment within which the DOD currently operates can no longer tolerate past practices of ignoring operating and support costs during the development of weapons systems. To illustrate this change in attitude, Kankey cites a 1975 statement by John L. McLucas, Secretary of the Air Force,

> management is the biggest challenge Air Force people face today... the foundation of our success as a deterrent force is not going to be determined by 'flying and fighting' but by how well we manage our limited resources [25:29].

As the pressure for cost effective weapons systems grew, a multitude of LCC models developed. With O&S costs currently constituting 57% of the total DOD budget and an even higher percentage of the total LCC of a system, they are singled out for special attention.

The LCC models for O&S costs are based on a cost element structure. The cost element structure is a listing of cost categories or elements, such as depot level maintenance, unit level consumption, unit mission personnel, and other cost categories, under which the costs for operating and supporting a system would be accumulated. In general, the cost element structure of LCC models was arbitrarily chosen and this caused problems in the interpretation and comparability of LCC model results. LCC models may be used to aid and/or accomplish a variety of purposes, such as, trade-off decisions and "to support budget estimates, Design-to-Cost (DTC) programs, and management reviews" (29:Ch 2, 3). However, different cost element structures make comparability difficult.

The results of LCC evaluations are used by the DSARC (JRMB) to make decisions on which systems should be continued into full scale development and production. Therefore, a standard cost element structure was needed in order to achieve equivalence between alternative system proposals. One of the early steps toward standardization was MBO 9-2, which called for improving the visibility and management of O&S costs.

Recktenwalt observes that MBO 9-2 "has been definitized in several other DOD and Air Force regulations, including DODD 5000.4, 5000.39, 5000.28, and AFR 800-8" (33:4). (DODD 5000.28 Design to Cost was replaced by DODD 4245.3 Design to Cost dated 6 April 1983.) He quotes from DODD 5000.4 (OSD Cost Analysis Improvement Group (CAIG)) that, "the CAIG acts as the primary advisory body to the DSARC on matters relating to cost" (33:4). The CAIG formulated O&S cost development guide (CAIG Guide) of 15 April 1980 set forth a cost element structure that must be adhered to in all proposals reviewed by the DSARC (now JRMB). The requirement for adherence to the CAIG approved cost element structure made it necessary to reformulate (translate) the previous LCC models which were based on arbitrary cost element structures.

Specific Problem

LCC-2 is a LCC model which was formulated prior to the CAIG approved cost element structure. LCC-2 is a very good model for use in costing avionics systems which will be employed on one specific type of aircraft. Currently, no comparable model exists which meets the CAIG standards (19).

> LCC-2 was developed to evaluate the costs of acquiring an avionics system and supporting it over its operational life. It is an accounting model and is useful in comparing support concepts (two versus three level maintenance), evaluating Reliability Improvement Warranty (RIW) , performing sensitivity analysis, and identifying important cost driving parameters in a system acquisition program. Calculations are performed down to the Shop Replaceable Unit (SRU) level and a variety of output products are available [22:Forward].

Research Questions

1. What is the standard CAIG cost element structure and its associated cost elements?

2. What is the cost element structure employed by LCC-2 and its associated cost elements?

3. What are the specific cost estimating relationships which yield the LCC-2 costs?

4. How may the cost estimating relationships currently employed in the LCC-2 model be modified to yield the standard CAIG approved cost elements and cost element structure?

Definitions

Life Cycle Cost (LCC). AFR 800-11, Life Cycle Cost Management Program states that LCC is "the total cost to the government for a system over its full life" (12:1).

Sims states , "life cycle cost is the total cost to the government of acquiring, operating, supporting and disposing of a system over its lifetime" (36:12). Boden (3:29) and Kankey (25:28) have similar definitions for LCC. "The objective of Life cycle costing is to lower a system's life cycle cost by striking a balance between acquisition and O&S costs" (36:12). The total life cycle cost estimates for a system are required early in the acquisition phase so that alternative systems may be compared with one another. Typically the life of a system is broken down into four parts or periods: research and development, production, operating and support, and disposal (12:1; 29:Ch 2, 1). The research and development (R&D) period of a project initiates the life cycle of a system and the accumulation of LCC. During the R&D period the feasibility of the proposed system to meet a specific need(s) of the DOD is determined. The system enters the acquisition phase if it demonstrated its feasibility. The acquisition phase, described by Department of Defense Directive (DODD) 5000.1, Major Systems Acquisition (10:4), consists of four phases: concept exploration, demonstration and validation, full-scale development, and production and deployment. In the concept exploration phase, alternative systems which could fulfill the need are examined. During the demonstration and validation phase, the system is prototyped (designed, built, and tested). In the full-scale development phase, the prototype model is built and tested. The system finally enters the production and deployment phase. Sometime during this phase, at a negotiated point in time, total responsibility for the system shifts from the acquiring command (AFSC) to the supporting command (AFLC). This is called Program Management Responsibility Transfer (PMRT). The O&S phase follows the production and deployment phase. The O&S phase is typically the longest and most costly phase of the system's life cycle. The system is disposed of following the O&S phase. The end of the operational life may result for several reasons, political, cost, environmental or obsolescence.

Life Cycle Cost Management.

> A cost management discipline used in managing a product throughout its life cycle. It involves the consideration of current and future cost consequences such as life cycle cost or applicable segments thereof, along with performance, schedule, and supportability aspects, in making decisions affecting the acquisition and follow-on support of the product. It requires a cost conscious attitude and a plan for reducing or controlling costs [12:1].

Cost Drivers. There are two different approaches to viewing cost drivers. The first approach defines a cost driver as the cost element which contributes the most to total cost. The second view defines cost drivers as the underlying factors, like maintainability, reliability and supportability, which have a major effect on cost. The drivers may be as abstract in nature as political considerations or as concrete as a jet engine (31:10). The cost drivers for new systems are often based on the past costs of similar systems in the inventory (19; 24). Cost driver identification is an important step in building the LCC model for a system.

Model. Benjamin Blanchard in his book, Design and Manage to Life Cycle Cost, defines

> a model, in principle, is a simplified representation of the real world which abstracts certain features of the situation relative to the problem being analyzed. A model can be used as a tool to gain knowledge through analysis and as a means of conveying information [2:81].

Similarly, Shannon states, "a model is a representation of an object, system or idea in some form other that that of the entity itself" (34:4). Barton believes "a model is a constructed specific expression of a theory or of one or more hypotheses" (1:26). Barton expands upon this definition by commenting

> most theories are general, in fact too general, to be tested in any meaningful way in their entirety. General theories are tested only through specific expressions of them, that is, through models designed to give operational opportunity to the implication of the theory [1:27].

Life Cycle Cost Models. LCC models are sets of systematic equations which use the cost related variables identified for the particular system in question to derive an accurate estimate of the system's cost drivers which yield the system's LCC. The model may be simple or highly complex (2:81; 29:Ch 1, 2; 3:26).

Cost Element Structure. The cost element structure is the framework upon which the LCC model is built. The cost elements are structured to accumulate the total life cycle costs for a system or subsystem. An example of one piece of the overall framework might be unit level consumption, which has as its cost element components, petroleum, oil, lubricants, maintenance material, and training ordnance (29:Ch 4, 3).

Cost Estimating Relationships. Cost estimating relationships are normally equations which yield the costs of a specific cost element. Blanchard describes cost estimating relationships as "basically 'rules of thumb' which relate various categories of cost to cost generating or explanatory variables of one form or another" (2:38).

Design to Cost (DTC). DODD 4245.3, Design to Cost, defines DTC as

> an acquisition management technique to achieve defense system designs that meet stated cost requirements. Cost is addressed on a continuing basis as part of a system's development and production process. The technique embodies early establishment of realistic but rigorous cost objectives, goals, and thresholds and a determined effort to achieve them [9:2-1].

Whereas, in the past, schedule and performance objectives were considered paramount, with the establishment of DODD 4245.3, cost was now given equal status (9:1). The Design to Cost (DTC) concept includes LCC as a system design parameter to be considered with schedule, performance, reliability, maintainability and others (2:12).

SCOPE

This thesis effort will be confined to modifying the LCC-2 model from the current cost element structure to one that is consistent with the CAIG approved O&S cost element structure. Such a translation is required prior to utilization in the current milestone reviews. At present, output from any model employed to justify a program's continuance through the DSARC (now JRMB) must be based on the CAIG approved cost element structure.

II. Background

Chapter Overview

This chapter contains a review of the literature concerning LCC, modeling, the LCC-2 model and CAIG approved cost element structure. The literature points out the importance of LCC and problems concerning implementation. Modeling is discussed to provide a framework for the understanding of sensitivity of models to variations and to aid in understanding the LCC-2 model. The LCC-2 and CAIG approved cost element structures will be discussed to provide a working knowledge of each to aid in translating the LCC-2 model into a model based on the CAIG approved structure.

Life Cycle Cost (LCC)

Doane questions the applicability of the basic life cycle concept of building on requirements and specifications, which is used in weapon system acquisition, when addressing a "rapidly changing, computer-intensive C3 system" (8:180).

> Once we agree that, even collectively, we are incapable of accurately stating what is needed (or will be needed), because the requirement itself is subject to constant change and redefinition on a time scale much shorter than the time required to develop the system, then the development process itself must be viewed as dynamic, and not amendable to an invariant sequence of activities... unlike the typical weapon system, it is difficult, and sometimes impossible, to develop a firm operational description of what a C3 system should do, or a boundary for its users [8:180-182].

Today's weapon systems are employing computers in steadily increasing numbers, and there seems to be no end in sight. Even though the present seems bleak we must remember that by pursuing a LCC management strategy we can achieve a balance between cost (acquisition and O&S), schedule, and performance which will yield efficient and effective weapon systems in a timely fashion. Kankey believes that "the most interesting trades are those between different portions of cost; i.e. trades that increase acquisition cost but decrease ownership cost" (25:29). In the past the necessity for LCC was driven by several factors, two of the most important ones being a steady increase of O&S costs as a percentage of DOD's total budget and the need to modernize the armed forces, which required either cuts in O&S costs or increased funding to finance the increased research and development (R&D) and production costs to modernize (36:12; 28:1; 17:vii,1).

One of the most widely used techniques for LCC is design to cost (DTC).

> Design to cost is a management concept for controlling acquisition and O&S costs through establishing quantified cost goals. The DTC goal is, simply stated, a "contract" between the Secretary of Defense and the program manager to produce a weapon system for a specified cost. It is based upon a given quantity, production rate, and schedule and is normally established very early in the development process [36:12].

Gansler and Sutherland define DTC as

> the management and control of future acquisition, operating and support costs during the design and

> development process under established and approved cost objectives. A design to cost goal is a specific cost number (in constant dollars for a specified number of systems at a defined production rate) established as early as possible in the acquisition process, but not later than the time of entry into the full scale development phase [21:2].

Shorey points out five key elements to consider when managing O&S (downstream) costs:

(1) O&S visibility,

(2) O&S cost-related thresholds,

(3) design trades to minimize LCC,

(4) contract and other incentives to minimize O&S costs, and

(5) logistics alternatives (35:10).

Each of these points must be addressed in the Decision Coordinating Paper (DCP), which is the contract between the Secretary of Defense and the military service/program manager (35:10).

O&S cost visibility is necessary in the initial stages of the Defense Systems Acquisition Review Council (DSARC) (now JRMB) process in order to weigh the proposed system against possible alternatives based on LCC considerations. In order to facilitate well defined cost elements and methods for computation of LCC, the Cost Analysis Improvement Group (CAIG) was established. MBO 9-2 has required an extensive data base of O&S weapons systems costs to be compiled. The database will use CAIG guidelines and eventually will "increase the credibility and usefulness of O&S cost projections as a DSARC management tool" (35:11).

Design tradeoffs and analyses are necessary to arrive at O&S cost-related thresholds. Related thresholds are

> specific measurable parameters directly affecting O&S cost... established as DCP thresholds, and that follow-up measurements will be made to confirm attainment. Examples of threshold parameters are reliability, maintainability, availability, maintenance manhours/flight hours, support equipment such as initial spares and test equipment, and crew size [35:10,12,13].

These tradeoffs and analyses must be accomplished early in the acquisition process in order to provide the O&S cost-related thresholds of a particular system. Given the particular thresholds the system may be weighed against other alternative systems which would also fill the specific DOD requirement. With the ARC-164 radio system, "the target mean time between failure (MTBF) chosen was 1000 hours because that point approximates the flattening out of the LCC cost curve" (35:14). As the MTBF rises, procurement costs rise in order to achieve the higher reliability. The rising costs may result for a number of reasons: increased design costs, premium quality components, and more expensive type technology. Generally with a higher MTBF, O&S costs fall. The fall in O&S costs results because the system breaks down less often. The problem is to minimize the sum of the acquisition, procurement and O&S costs (i.e. LCC). The need for comparability of the minimized LCC of alternative systems is complicated by two factors which arise as a result of their differing timing of expenditures over a span of time.

For example, imagine two alternative systems, A and B. For the purposes of this discussion both systems will have equal effectiveness against the proposed threat and only one unit will be procured regardless of which is chosen. Additionally, assume that in today's dollars, system A cost one million dollars and system B $750,000. However, system A's project manager will spend significantly more in both the design and materials than the alternative system B's program manager (in anticipation of lower O&S costs and subsequently lower LCC than system B). LCC estimates of O&S costs over an assumed ten year useful life, are 25,000 and 75,000 then year dollars per year for A and B respectively. A quick computation gives equal LCC of 1.25 million dollars per system disregarding any disposal costs. It would appear that neither system has an advantage over the other. However, we have neglected the differing schedules of unequal O&S expenditures.

The two previously alluded to factors, inflation and the time value of money, will affect each project's LCC differently. As inflation rises, the value of a dollar shrinks. The inflation rate varies over time. The idea behind the time value of money is that "a dollar in hand today is worth more than a dollar to be received at sometime in the future because money has a cost - interest" (27:80). These two factors have the effect of encouraging the delay of spending in programs toward the end where the dollars are not worth as much (27:80). Extra dollars spent up front in better design and materials must be justified considering the effects of inflation and the time value of money. Due to the two factors which result from changing economic conditions and the timing of expenditures, projected LCC's of 1.25 million dollars are not necessarily equal.

Compensation may be provided for both of these factors. Inflation's effect is taken care of by converting future dollars into constant dollars which are adjusted for inflation. The appropriate conversions and figures are published in Air Force Regulation (AFR) 173-13, USAF Cost and Planning Factors. The CAIG recommends conversion to constant dollars of the present year. The CAIG also notes, "constant dollars make future costs look more reasonable and give decision makers a benchmark for comparison" (30:79).

The second factor, the time value of money, can be adjusted for by discounting the constant dollar stream. "By discounting, all time phased expenditures are indexed to the present, the only fair method of evaluation if the decision is being made today" (30:80). The discount rate is given by AFR 178-1 as 10%. To give a final touch of realism to the problem assume a 5% inflation rate. The LCC for each system could now be computed and the systems fairly compared.

Contracts may be written to make LCC a real factor in source selection. The ARC-164 radio and the F-16 are prime examples of the successful integration of LCC factors into a contract (23:8,15; 35:14,17). One type of incentive for contractors

> ...includes warranties on new equipment--ranging from a commitment to fix all failures which occur during a specified period of time (for an agreed fixed price) to more complex agreements which require additional guarantees for MTBF or other performance features [35:16].

Shorey notes that, for maximum impact, support concepts must be addressed during the conceptual phase of design when the basic approach to modularity and built-in testing and sensing should be decided, and the logistic approach derived from that point (35:16). LCC, readiness, design tradeoffs, and other threshold factors, such as reliability and maintainability, must all be considered and balanced to give the most effective system within the determined cost bounds. Shorey believes this "has had the least management emphasis and has perhaps the greatest potential payoff" (35:16).

Modeling

The DOD has had some difficulties in implementing O&S cost management (36:12). Boden suggests that "the LCC model for a system will have different sensitivities than that of the subsystem. The LCC model almost has to be peculiar to the product if it is to be reasonably accurate" (3:29). As a result of the increasing constraints upon the defense budget the economic analysis of weapons systems in the mid 60's to mid 70's was refined and perfected at a fast pace (37:26).

Collins groups the types of models used by the Air Force for economic analysis into three general categories:

(1) cost factor,

(2) accounting, and

(3) optimizing (7:54).

Cost factor models based on Air Force-derived cost factors are used to compute weapons systems O&S cost estimates. The estimate is the sum of cost elements achieved by multiplying the derived cost factors by parameters like flying hours, weapons purchased, or flyaway cost of the new system. The model is easy to use, but reflects only the system cost elements and not the subsystem cost elements. Collins observes that

> by not breaking out costs in detail at the subsystem and line-replaceable unit (LRU) level, this approach tends not to capture the O&S cost impact of peculiar reliability and maintainability (R&M) characteristics of a new weapon system [7:54,55].

The accounting type model is more complex than the cost factor type and is used to a greater extent. This type of model allows O&S cost to be broken down to the LRU level. The costs of these elements/components (eg. initial and replenishment spares costs, on and off-equipment maintenance cost, etc.) are totaled to compute the total O&S costs of the system. To accomplish the low level visibility four categories of input parameter estimates are needed:

(1) program elements,

(2) contractor-furnished subsystem elements,

(3) contractor-furnished LRU elements, and

(4) Air Force-furnished constant elements (7:55).

Parametric cost modeling based on cost-estimating relationships (CER) is a category of accounting type models. This type of modeling attempts to use easily quantified variables, like size and weight, to estimate more qualitative types of variables such as production schedule, or more complex quantitative variables such as total system LCC. "The key feature of a parametric model is its ability to be calibrated (or tuned) to specific empirical values obtained through the study of similar or analogous situations in the past" (26:1527-28). May commented concerning parametric modeling. "A CER is simply a mathematical equation that relates one or more characteristics of an item to a desired element of cost" (29:Ch 3, 1). Additionally, May relates that early in a program, CER's may be the only tool available, and, despite the difficulty in developing them, their application is straight forward (29:Ch 3, 3-5).

The disadvantages of the accounting model are a result of its detailed breakdown. This requires large amounts of data which may not be standardized. Additionally, validation of the large amount of input data becomes a problem (7:56-57). The work of the CAIG will help in standardization of input data, which will solve the first problem. The second problem is more difficult to handle.

The F-16 program reduced the cost areas down to six. These represented the majority of the system costs. This enabled validation of the input data at the expense of some loss of information (7:57).

Optimizing models try to maximize across a subset of support alternatives in order to minimize O&S costs. The single item-single indenture model is an example of an optimizing type model. The model is easy to use, like the cost factor type models. When applied to LRU's, "it simply adds up the various costs of each of three maintenance alternatives (levels of repair) for a given LRU--discard at failure, repair at base, and repair at depot-- and identifies the least cost of the three policies" (7:57). The limitations of this type model are the requirement of an allocation procedure and the lack of capability to cost out repairs below the LRU level (7:57-58).

Similarly to Collins, Cira notes that LCC models may be broken down into nine categories: accounting, simulation, economic analysis, cost estimating relationship, reliability improvement, level of repair analysis, maintenance manpower, inventory management, and reliability improvement warranty (6:44-45). The nine categories seem to be more descriptive and possibly more comprehensive than the three previously mentioned cost factor, accounting, and optimizing categories, with the exception of the cost factor category. This category seems unique when compared to the nine listed by Cira. The accounting categories are roughly equivalent, except that, Cira separates out CER models, whereas Collins groups them both into accounting. Optimizing models and level of repair analysis models are equivalent. The remaining six categories listed by Cira are difficult to place into the three more general categories of Collins.

Barton stated, "a model is a constructed specific expression of a theory or of one or more hypotheses" (1:26). Vollmann remarked, "models are systems of abstracted entities, built for particular purposes or interests in real world systems such as design, operation, training, prediction, or sales" (38:54). Given these definitions of a model to work with Byrd and Moore describe when a model can be called successful.

> There are few instances when a model can unequivocally be called successful. In such cases, there is usually a "before" situation which can readily be contrasted with an "after" situation, showing conditions to be better after the advent of the model. For instance, a company that uses a model to increase production can clearly call the model application a success. Rarely is the judgement of models so simple [4:42].

LCC-2 Model

LCC-2 is an accounting type life cycle cost model. The model is extensively used by Aeronautical Systems Division (ASD) system program offices for estimating the acquisition and O&S costs of avionics systems (19). The LCC-2 model is employed normally for estimating the cost of a new system to be employed on a specific aircraft. The model does not include Research Development Testing and Evaluation (RDT&E)

or disposal costs. The production or acquisition costs are included, but normally only through obtaining the actual costs to procure the system. The O&S costs are determined through cost estimating relationships (19). Mr. Huff noted that a variant of the LCC-2 model was employed by a contractor recently to provide LCC estimates for a DSARC (now JRMB) milestone review (24). The need to adjust the resulting output to fit the requirements of the CAIG standards caused great confusion and delay (24).

Mr. Huff discussed a few problems concerning "bugs" that are currently being fixed in the code of the model. Apparently there are some minor problems when altering the maintenance support levels from two to three. This is a very useful capability to have in a model for use in the current DOD environment. Cost savings can occasionally result from consolidating supply and repair at higher echelons, thereby reducing intermediate shop levels. However, as the model can show, it is more cost effective in some cases to have intermediate level shops.

Another difficulty appears with the costs for spares. The CAIG has given guidance concerning the allocating of spares into pipeline spares and condemnation spares. Pipeline spares are those spares needed to maintain required availability of spares at any particular level based on factors like failure rates, time to repair, and time to transport from one level to another and back again. The pipeline spares are considered acquisition costs since they are acquired with the initial procurement of the system. Condemnation or replacement spares are the spares that will replace the initial pipeline spares as they wear out and are no longer repairable or are destroyed. The initial LCC-2 model only considered spares as acquisition items. This was the philosophy employed by many LCC models. The difficulty with that approach was due to the time value of money. The idea behind the time value of money is that one dollar today is worth more than one dollar in the future. The present worth of the spares under the old model was equal to their procurement cost in the year the system procurement was made. However, the actual cost several years later to buy the needed spares to replace destroyed and non-repairable units was higher as a result of inflation. The CAIG initiative of separating spares into pipeline and condemnation spares solved this problem. The attempt at modifying the program to incorporate the CAIG guidance resulted in the double purchasing of some types of spares. This double purchasing yields an inaccurate cost estimate which must be adjusted (24).

CAIG Cost Element Structure

The cost element structure (CES) of the LCC-2 model was formulated prior to the strict enforcement of adherence to CAIG guidance for DSARC, now JRMB, milestone approval decisions. The resulting outputs from the model must be manipulated to achieve acceptable figures for comparison purposes. See Table I for the CES of the LCC model.

TABLE I

Cost Element Structure of LCC-2 Model

INITIAL TRAINING	WARRANTY
DATA ACQUISITION	FLIGHT LINE MAINTENANCE
ITEM ENTRY	BASE LEVEL MAINTENANCE
DATA MANAGEMENT	DEPOT LEVEL MAINTENANCE
PRIME HARDWARE	ITEM MANAGEMENT
SUPPORT EQUIPMENT	DATA MANAGEMENT
SPARES	PACKING & SHIPPING
INSTALLATION	SUPPORT EQUIPMENT MAINTENANCE

(19: Sec 3, 46)

As mentioned earlier, comparability and interpretability between various alternative systems with dissimilar CES's was difficult. The formation of the CAIG under the Office of the Secretary of Defense gave them the power necessary to enforce standardization across the DOD. Shortly following its formation the CAIG began disseminating guidance concerning LCC CES standardization. One of the earliest CAIG approved CES's was for aircraft systems. See Table 2 for the CES cost elements.

The CAIG has given cost structure guidance for alternate mission equipment (AME) and stand-alone electronic systems which may be more appropriate for life cycle costing of the type of systems for which LCC-2 is now employed. This guidance has not been formalized (16; 19). See Table 3 for the CES of AME.

TABLE II

Aircraft O&S Cost Development Guide

- UNIT MISSION PERSONNEL
  - Aircrew
  - Maintenance
  - Other Unit Personnel
- UNIT LEVEL CONSUMPTION
  - Petroleum, Oil, & Lubricants
  - Maintenance Material
  - Training Ordnance
- DEPOT LEVEL MAINTENANCE
  - Airframe Rework
  - Engine Rework
  - Component Repair
  - Support Equipment Rework
  - Software
  - Modification Labor
  - Other Depot Maintenance
  - Contracted Unit Level Support
- PERSONNEL ACQS AND TRAINING
  - Acquisition
  - Individual Training
- SUSTAINING INVESTMENT
  - Replenishment Spares
  - Replacement Support Equipment
  - Modification Kits
  - Other Recurring Investments
- INSTALLATION SUPPORT PERSONNEL
  - Base Operating Support
  - Real Property Maintenance
  - Medical
- INDIRECT PERSONNEL SUPPORT
  - Miscellaneous O&M
  - Medical O&S Non-Pay
  - Permanent Change of Station
  - Temporary Additional Duty Pay
- DEPOT NON-MAINTENANCE
  - General Depot Support
  - Second Destination Transportation

(30:9)

TABLE III

CAIG CES Guidance for Alternate Mission Equipment

DEPOT MAINTENANCE
- Mission equipment
- Component equipment
- Support equipment
- Software
- Modifications
- Other depot
- Contracted unit level support

SUSTAINING INVESTMENT
- Replenishment spares
- Replacement support equipment & spares
- Modification kits & other recurring investment

DEPOT NON-MAINTENANCE
- General depot support
- 2nd destination transportation

UNIT MISSION PERSONNEL
- Operators
- Maintenance
  - organizational
  - intermediate
  - other maintenance
- Other
  - unit staff
  - security
  - other

UNIT LEVEL CONSUMPTION
- Energy Consumption
- Maintenance Material (BMS)

INSTALLATION SUPPORT PERSONNEL
- Base operating support
- Real property maintenance
- Medical

INDIRECT PERSONNEL SUPPORT
- Miscellaneous O&S
- Medical O&S non-pay
- PCS

DEPOT NON-MAINTENANCE
- General depot support
- 2nd destination transportation

ACQUISITION AND TRAINING
- Acquisition
- Specialty training

(13:8-9)

III. METHODOLOGY

This thesis effort consisted of four basic tasks:

(1) literature review,

(2) analysis of both the CAIG approved and LCC-2 model cost element structures, the LCC-2 model cost estimating relationships,

(3) the modification of the cost estimating relationship equations to yield output which complied with the CAIG approved cost element structure, and finally,

(4) the creation of additional CER's to yield cost for CAIG cost elements not addressed initially by the LCC-2 model and which have an influence on the LCC of avionics systems.

The final modifications were documented and discussed.

Literature Review

The literature review provided the general background information on LCC, modeling, LCC-2 and the CAIG approved cost element structure. Additional information was obtained from personal interviews and phone conversations with LCC analysts and experts Maj. Robert Edmund and Lt. Larry Fifer of ASD/ALTB and Mr. John Huff of AFALC/LSS (16; 19; 24). Budget information was obtained from Mr. Austin Wasley of AF/ACBMC. The information gleaned from the literature review coupled with the personal experience and advice gained from interviews aided in the selection of a realistic approach for translating the LCC-2 model to CAIG compliance. Due to the large volume of information on LCC no difficulties were encountered in building a general background knowledge concerning LCC, modeling, LCC-2 and CAIG approved CES's.

Analysis of LCC-2 and CAIG CES

The analysis of the CAIG and LCC-2 model cost element structures was a challenging task, as the area of LCC and logistics was a new venture for the author. Again, the literature review and interviews were invaluable toward educating the author and providing a foundation upon which to build the transformed model. The analysis and understanding of the cost estimating relationships were even more challenging. As the various interviews with LCC personnel suggested, the model was "intransigent" and coded in a manner conducive to maintaining the original developer as the only entity capable of performing significant modification to the model's code (19; 24). Throughout the analysis of the two cost element structures, a conceptual matrix of relationships between the CAIG approved and LCC-2 model cost elements was maintained. The CAIG standards were viewed as headings for the rows of the matrix while the LCC-2 cost elements were viewed as headings for the columns. Whenever a LCC-2 cost element matched or partially equated to a CAIG standard cost element a mental note was kept concerning the degree of similarity. This aided in the initial translation of the LCC-2 model and pointed to areas of the model which required in-depth analysis and reformulation. This approach also identified the areas which the LCC-2 model did not address, and which would require formulation of original CERs.

Modification of LCC-2 CERs

The modification of the LCC-2 cost estimating relationships was relatively straight-forward and allowed time to work on additional CERs to yield output for CAIG cost elements not addressed by the LCC-2 model CER's. A portion of the cost estimating relationships employed yielded output which fell under two CAIG approved cost elements. Those cost estimating relationships were reformulated in order to yield the new CAIG approved cost element components. This separation was not particularly difficult.

Creation of Additional CERs

The creation of the additional CER's in some cases required the formulation of new assumptions and approaches to estimating the cost elements. The new estimating equations were formulated under two constraints. The first constraint was to add as few new variables as possible. The idea was to keep the equations simple and understandable. The second constraint was to utilize variables for which data was readily available, if at all possible. This was done to keep the application of the model easy and simple. The application of the model should not require extensive searches for data and subsequent manipulation of the data.

Meeting the Research Objectives

The first three research questions were answered by completing tasks one and two of the methodology. The remaining fourth research question was answered by completing tasks three and four, which were based on the foundation laid by tasks one and two.

IV. Model Analysis

This thesis effort modified the LCC-2 life cycle cost model into a variant which would comply with the OSD/CAIG standard cost element structure for aircraft systems. To accomplish this modification, it was necessary to analyze each of the LCC-2 cost estimating relationships (CERs) to determine which of the CAIG standard cost elements a particular CER applied to. The LCC-2 model consisted of purely production CERs and CERs that were a mix of production and O&S relationships. If necessary, the CER was broken down into components such that each component covered only one standard O&S cost element. The CAIG standard cost element structure handles only O&S costs. However, as stated, the LCC-2 model estimates both acquisition or production costs as well as O&S costs. Therefore, some LCC-2 CERs were left over because they dealt with only production costs. The production components of the mixed relationships and the purely production CERs were kept for completeness. The analysis of the LCC-2 CERs yielded nine production and eight O&S CERs.

Additionally, some of the new standard CAIG cost elements were not addressed by the LCC-2 model CERs. New CERs were devised to yield output for these cost elements. When developing these CERs the level of effort was weighted by their relative percentage of the total annual O&S costs.

Considering the additional CERs, software maintenance and modification labor and kits, and unit mission maintenance personnel were the largest percentage elements. When aircraft such as; B-52G, KC-135, C-5A, and F-15 are evaluated, the remaining cost elements; maintenance materials, personnel acquisition and training, permanent change of station (PCS), and unit mission "other personnel" were all typically below five percent of the total annual O&S LCC (29:Ch 6, 9).

Discussions with LCC analysts and avionics software analysts identified the major cost drivers of avionics systems to be the areas of software and hardware maintenance, and system and support equipment spares.

LCC-2 Cost Estimating Relationships

The LCC-2 cost estimating relationships consistently combined initial (acquisition/production) costs and O&S costs. It was necessary to separate out the initial costs from the O&S costs to comply with the CAIG standards. In most cases the separation was relatively easy. However, in a few cases the final CERs were based on intermediate variables which contained additional intermediate variables. It was necessary to analyze each of these intermediate stages and isolate the initial production costs from the O&S costs. Subsequently the modified intermediate levels were recombined to yield the modified CERs which would comply with the CAIG standard CES. The remaining intermediate level components which dealt with production costs were also recombined and kept intact. The production cost CERs have been retained in this model to yield some definition for the various production costs. Even though the CAIG standard CES for aircraft systems deals only with O&S costs, the LCC analyst needs to have the total LCC available. As noted before, this consists of R&D, production, O&S, and possibly disposal costs. Disposal costs are normally insignificant and considered to be zero. Therefore, this model, by retaining the production CERs will enable the LCC analyst to estimate total system LCC given the R&D costs.

Modified LCC-2 O&S CERs

The following is a listing of the modified LCC-2 O&S CERs. An indepth description is provided in Appendix B. A listing and description of all model variables is provided in Appendix A.

This model will employ the same notational convention as the LCC-2 model.

> All cost elements are computed on an annual basis with the symbol C_{ik} denoting the value of cost element i in year k of the program. Several cost elements are incurred only in certain years of the program, depending on factors such as whether a warranty is used and the warranty length. In these cases, a notational convention, established for conciseness, is defined as follows:
>
> $$\delta(\text{statement}) = \begin{cases} 1 \text{ if statement is true} \\ 0 \text{ otherwise} \end{cases}$$
>
> where the argument "statement" is any logical expression. For example, if WP is the length of the

warranty and k is the year of the program, then multiplication of a cost quantity by $(k > WP)$ indicates that the cost is zero until after expiration of the warranty. This convention is also used to incorporate logical relationships pertaining to the system support concept into the life cycle cost model equations [22:Ch 2, 13-14].

System Spare Cost in Year k. This CER provides the system's spares cost element, and is an adaptation of the LCC-2 user's guide equation C_{2k} (22:Ch 2, 15-6).

$$C_{1k} = \frac{NAC_k}{NTOT} \times \left(\sum_{i \in I_1} NCS_i \times CRU_i \right) + \delta(k = WP+1) \times \left(\sum_{j=1}^{k} \frac{NAC_j}{NTOT} \right) \times \left(\sum_{i \in I_s} NCS_i \times CRU_i \right) + \delta(k \geq WP+1) \times \left(\frac{NAC_k}{NTOT} \right) \times \sum_{i \in I_s} NCS_i \times CRU_i \qquad (1)$$

Unit Mission Personnel Flight Line Maintenance. This CER provides the system's flight line personnel cost element. It is an adaptation of the LCC-2 user's guide equation C_{6k}, maintenance man hour adjusting factors from May (29), and average composite wage rate from Air Force Regulation (AFR) 173-13 (22:Ch 2, 27-8; 29:Ch 7, 7; 14:40). AFR 173-13 provides an average annual composite wage rate of 24,309 dollars for enlisted personnel. May notes that after corrections for sick leave, travel, and training, 144 hours are left in the month for maintenance. However, he also notes that these 144 hours must be derated by a factor of .75 to account for the cyclical nature of maintenance.

$$C_{2k} = \left(RLS_1 \times \sum_{m=1}^{12} \frac{NCUM_{km} \times NQ_1 \times OH \times RTS_1}{G_{km} \times MTBF_1} + \sum_{i \in I_1} ENR_{ik} \times RRS_i \right) \times \frac{24309}{12 \times 144 \times .75} \qquad (2)$$

Unit Mission Personnel Base Level Maintenance. This CER provides the system's base level maintenance personnel cost element. It is an adaptation from the LCC-2 user's guide equation C_{7k}, maintenance man hour adjusting factors from May (29), and average composite wage rate from AFR 173-13 (22:Ch 2, 27-8; 29:Ch 7, 7; 14:40).

$$C_{3k} = \left(\sum_i \left(\delta(LV_i = 1) \times ENR_{ik} \times FVS_i + \delta(LREM_i = 1) \times ENR_{ik} \times RRS_i \right) \right) \times \frac{24309}{12 \times 144 \times .75} \qquad (3)$$

Depot Level Maintenance in Year k. This CER provides the system's depot level maintenance cost element. This is equation C_{8k} from the LCC user's guide addendum (22:Addm 2, 6).

$$C_{4k} = \delta(k > WP) \times \sum_i ENR_{ik} \Big(\delta(k \leq ISP) \Big(\delta(LV_i = 2) \times FVS_i \times SDR + (1 - UFP_i) \times NRTS_i \times \big(RLS_i \times SDR + SDMC + RMS_i \big) + \delta(LREM_i = 2) \times RRS_i \times (SDR + SDMC) \Big) + \delta(k > ISP) \Big(\delta(LV_i = 2) \times FVS_i \times SDR2 + (1 - UFP_i) \times NRTS_i \times \big(RLS_i \times SDR2 + SDC2 + RMS_i \big) + \delta(LREM_i = 2) \times RRS_i \times (SDR2 + SDC2) \Big) \Big) \qquad (4)$$

Item Management in Year k. This CER provides the system's item management cost element. This is equation C_{13k} from the LCC-2 user's guide (22:Ch 2, 32).

$$C_{5k} = \delta(k > WP) \times NI \times SIM \tag{5}$$

Data Management in Year k. This CER provides the system's data management cost element. This is equation C_{14k} from the LCC-2 user's guide (22:Ch 2, 33).

$$C_{6k} = (NPB + NPO) \times SDM + \delta(k > WP) \times NPD \times SDM \tag{6}$$

Packaging and Shipping in Year k. This CER provides the system's packaging and shipping cost element. This is equation C_{15k} from the LCC-2 user's guide (22:Ch 2, 34).

$$C_{7k} = \sum_{i} \delta(LREM_i \leq 1) \times CPS_i \times ENR_{ik} \times (1-UFP)$$
$$\times \left(2 \times NRTS_i + COND_i + \delta(LR_i=2) \times 2 \times RTS_i\right.$$
$$\left. + \delta(LV_i=2) \times 2 \times \frac{UFP_i}{1 - UFP_i} + \delta(LV_i=2) \times COND_i\right) \tag{7}$$

Support Equipment Maintenance in Year k. This CER provides the system's support equipment maintenance cost element. This is equation C_{16k} from the LCC-2 user's guide (22:Ch 2, 34-5).

$$C_{8k} = \sum_{j=1}^{NSE} NREQ_{jk} \times CSE_j \times COM_j \tag{8}$$

Modified LCC-2 Production CERs

The following is a listing of the modified LCC-2 production CERs. An indepth derivation is provided in Appendix C for each CER.

Hardware Acquistion Cost in Year k. This CER provides the system's hardware acquisition cost. This is equation C_{1k} from the LCC-2 user's guide (22:Ch 2, 14).

$$C_{18k} = NAC_k \times ACS \tag{9}$$

Initial Spares Cost in Year k. This CER provides the system's initial spares cost. This is an adaptation of the C_{2k} equation from the LCC-2 user's guide (22:Ch 2, 15).

$$C_{19k} = \frac{NAC_k}{NTOT} \times \sum_{i \in I_1} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right)$$
$$+ \delta(k=WP+1) \times \sum_{j=1}^{k} \frac{NAC_j}{NTOT} \sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} \right.$$
$$\left. + NRSD_i \times CRU_i \right) + \delta(k > WP+1) \times \frac{NAC_k}{NTOT}$$
$$\sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right) \tag{10}$$

Support Equipment Acquisition Cost in Year k. This CER provides the system's support equipment acquisition cost. This is equation C_{3k} from the LCC-2 user's guide (22:Ch 2, 24).

$$C_{20k} = \delta(k \geq ISP) \frac{NAC_k}{NTOT} \times \sum_{j \in J_b} \sum_{m=1}^{ISITE} CSE_j \times n_{jm}$$
$$+ \delta(k=WP+1) \times \left(\sum_{i=1}^{k} \frac{NAC_i}{NTOT} \right) \times \left(\sum_{j \in J_d} n_j \times CSE_j \right)$$
$$+ \delta(k > WP+1) \times \left(\frac{NAC_k}{NTOT} \right) \times \left(\sum_{j \in J_d} n_j \times CSEj \right) \tag{11}$$

System Installation Cost in Year k. This CER provides the system's installation cost. This is equation C_{4k} from the LCC-2 user's guide (22:Ch 2, 26-7).

$$C_{21k} = NAC_k \times SIN \qquad (12)$$

Warranty Cost in Year k. This CER provides the system's warranty cost. This is equation C_{5k} from the LCC-2 user's guide (22:Ch 2, 27).

$$C_{22k} = \delta(WP > 0) \times \frac{NAC_k}{NTOT} \times WPR \qquad (13)$$

Initial Training Cost in Year k. This CER provides the system's initial training cost. This is equation C_{9k} from the LCC-2 user's guide (22:Ch 2, 29-30).

$$C_{23k} = \delta(k=1) \times BTC + \delta(k=WP+1) \times DTC \qquad (14)$$

Technical Data Acquisition in Year k. This CER provides the system's technical acquisition cost. This is equation C_{10k} from the LCC-2 user's guide (22:Ch 2, 30).

$$C_{24k} = \delta(k=1) \times (DCB + DCO) + \delta(k=WP+1) \times DCD \qquad (15)$$

Initial Item Management in Year k. This CER provides the system's initial item management cost. This is equation C_{11k} from the LCC-2 user's guide (22:Ch 2, 31).

$$C_{25k} = \delta(k=WP+1) \times NI \times SIE \qquad (16)$$

Initial Data Management in Year k. This CER provides the system's initial data management cost. This is equation C_{12k} from the LCC-2 user's guide (22:Ch 2, 31-2).

$$C_{26k} = \delta(k=1) \times SID \times (2 \times NPB \times NBASE + NTOT \times NPO) \times \delta(k=WP+1) \times 5 \times NPD \times SID \qquad (17)$$

The last CER, C_{29k}, sums up the total O&S cost, C_{27k}, over the lifetime of the system and C_{28k}, the sum of the production costs. Equations 18 and 19 shown below each utilize the form of equation C_k from the LCC-2 user's guide (22:Ch 2, 35).

$$C_{27k} = \sum_{i=1}^{17} C_{ik} \tag{18}$$

$$C_{28k} = \sum_{i=18}^{26} C_{ik} \tag{19}$$

$$C_{29k} = C_{27k} + C_{28k} \tag{20}$$

Derivation of Additional CERs

As noted previously the LCC-2 model CERs failed to cover several cost elements of the new CAIG standard aircraft CES. The remaining key areas of software maintenance, modifications, modification kits, maintenance material, contracted unit level support, personnel acquisition, and permanent change of station (PCS) will now be addressed.

Software Maintenance. Software maintenance LCC is a difficult problem. Barry W. Boehm in his book Software Engineering Economics notes

> ...software maintenance is not optional. For each dollar spent on software development, another dollar needs to be budgeted just to keep the software viable over its life-cycle; after that another optional dollar can be spent on desirable enhancements over the life-cycle [4:550].

One good non-proprietary model exists in the field to estimate software maintenance LCC. The model is named COCOMO for Constructive Cost Model. The original COCOMO model was modified and the new intermediate model which contained 15 additional predictor variables estimated costs within 20% of actuals 68% of the time (4:614-15). However, the model uses a variable ACT (Annual change traffic) for which data is not easily or perhaps even possibly not available. ACT is the percentage of the total software lines of code which change in the period of one year. This data is not maintained in any known database and would be difficult to find.

For the purpose of this model a default value will be assumed for the ACT variable. The default value will be used in the absence of a better estimate of the ACT variable. This value was estimated as ten percent (.1). This value is based on an assumed 15 year life cycle for avionics systems and the ratio of maintenance versus development costs of 60% to 40% (18:297). This ratio means that in the lifetime of a piece of software, the amount spent for maintenance is one and one-half times as much as for development. If the costs per line of code are equal for development and maintenance, this ratio could suggest that the software code is changed one and one-half times over its useful life. This would equate to an average rate of change of ten percent a year throughout the life cycle, yielding an ACT value of .10.

The remainder of the data needed for the COCOMO estimate of annual man-months of software maintenance effort are relatively easy to obtain. The necessary equations from the COCOMO model for generating annual maintenance effort are listed below (4:536-38):

$$(MM)_{AM} = 1.00 \times (ACT) \times (EAF)_M \times (MM)_{NOM}$$

$(EAF)_M$ = RELY x MODP (See Tables IV & V for values).

$(MM)_{NOM} = 3.2 \times (KDSI)^{1.05}$ Organic (defined below)

$3.0 \times (KDSI)^{1.12}$ Semidetached "

$2.8 \times (KDSI)^{1.26}$ Embedded "

where

$(MM)_{AM}$ = Annual maintenance effort
$(EAF)_M$ = Maintenance effort adjustment factor
RELY = Required software reliability factor
MODP = Modern programming practices factor
KDSI = *Thousands of delivered source instructions*

(4:536-38)

TABLE IV

RELY Maintenance Effort Multipliers

Very Low	Low	Nominal	High	Very High
1.35	1.15	1.00	0.98	1.10

(4:538)

The output of this model is in man-months of time therefore, the output, annual maintenance man-months must be multiplied by the appropriate rate for depot level software analysts/programmers. This value will be assumed to equal the standard depot level maintenance rate for labor which is available from the VAMOSC data base for each depot. To convert the man months to man hours a conversion factor of 152 was utilized (4:59).

The resulting CER utilizes the maintenance man hours from the COCOMO model and the standard depot rate to compute the software maintenance cost (4:59,536-38).

TABLE V

MODP Maintenance Effort Multipliers

Product Size (DSI)	Rating				
	Very Low	Low	Nominal	High	Very High
2K	1.25	1.12	1.00	0.90	0.81
8K	1.30	1.14	1.00	0.88	0.77
32K	1.35	1.16	1.00	0.86	0.74
128K	1.40	1.18	1.00	0.85	0.72
512K	1.45	1.20	1.00	0.84	0.70

(4:538)

$$C_{9k} = 152 \times SDR \times (MM)_{AM} \tag{21}$$

The intermediate variable $(MM)_{NOM}$ calculation is dependent on the type of system software development one is considering. Systems may have organic, semidetached, or embedded software development. Organic projects are characterized by

A generally stable development environment, with very little concurrent development of associated new hardware and operational procedures.
Minimal need for innovative data processing architecture or algorithms.
A relatively low premium on early completion of the project.
Relatively small size. Very few organic-mode projects have developed products with more than 50 KDSI of new software [4:78-9].

The semidetached development effort may be characterized by all or part of the following

The team members all have an intermediate level of experience with related systems.
The team has a wide mixture of experienced and inexperienced people.
The team members have experience related to some aspects of the system under development, but not others [4:79].

The embedded type project effort best characterizes avionics systems. Boehm notes the following characteristics of embedded projects.

The major distinguishing factor of an embedded-mode software project is a need to operate within tight constraints. The product must operate within (is embedded in) a strongly coupled complex of hardware, software, regulations, and operational procedures, such as an electronic funds transfer system or an air traffic control system. In general, the costs of changing the other parts of this complex are so high that their characteristics are considered essentially unchangeable, and the software is expected both to conform to their specifications, and to take up the slack on any unforeseen difficulties encountered or changes required within the other parts of the complex [4:79].

Having the value of KDSI, which is the number of lines of source code for the program in thousands, and the project type, the nominal man-months of effort ($(MM)_{NOM}$) can be computed. The next intermediate variable, the effort adjustment factor $(EAF)_M$, is the product of two values. These two values, RELY and MODP, are obtained from look-up Tables IV and V respectively (4:538).

The calculation of development man-months $(MM)_{DEV}$ is now possible and following that the calculation of annual maintenance man-months $(MM)_{AM}$ is performed.

Modifications. Modifications to a system can fall into two classes at the depot level, class IV or V. Only class IV modifications "required for safety of flight, to sustain the reliability and maintainability characteristics of the system, or to reduce the cost to maintain the system" are included as O&S costs (29:Ch 9, 7). In the past the cost of modification labor was difficult to isolate (29:Ch 9, 7). Currently VAMOSC is outputting a value for each depot broken down by five digit work unit codes (WUC) for both class IV and V modifications.

This model will utilize a simple formula, C_{10k}, for computing the modification labor value in year k.

$$C_{10k} = NMOD_{jk} \times HMOD_{jk} \times SDR \times \quad (k \leq WP)$$
$$+ NMOD_{jk} + HMOD_{jk} \times SDR2 \times \quad (k > WP) \qquad (22)$$

where

$NMOD_{jk}$ = Number of type j modifications in year k.

$HMOD_{jk}$ = Number of hours required to perform the type j modification in year k.

SDR = Standard depot labor rate in dollars per manhour for the initial support period.

SDR2 = Standard depot labor rate in dollars per manhour for final support period.

Modification Kits. The relationship for computing the costs of modification kits in year k is C_{11k}.

$$C_{11k} = CMOD_{jk} \times NMOD_{jk} \tag{23}$$

where

$CMOD_{jk}$ = The cost of a type j modification kit in year k.

Contracted Unit Level Support. The value for contracted unit level support is negotiated between the government and a contractor. The method for computing the value is contained in the support contract. With the KC-10, "this was a set of fixed values and equations that accounted for the number of main operating bases, the number of aircraft, and the total number of flying hours" (29:Ch 9, 12). The CER for contracted unit level support will be C_{12k}, although in reality, an equation, equations or a single value may be obtained from the support contract. This equation is based on the same methodology as equation C_{5k} from the LCC-2 user's guide (22:Ch 2, 27).

$$C_{12k} = (SCP > 0) \times \frac{NAC_k}{NTOT} \times CSC \tag{24}$$

Personnel Acquisition and Training. To determine the personnel acquisition and training cost element, it was necessary to assume that only enlisted non-aircrew personnel would be required for the avionics system's maintenance. Therefore, the total maintenance manhours logged against a specific avionics system could be added together and subsequently divided by (144 x 12 x .75) hours per year to obtain the number of full time personnel required to maintain the system (29:Ch 7, 7). The rational for the above figure is justified by May (29) and takes into account sicknesses, leave, training, and the randomness of the workload. Normally 144 hours per month are available for maintenance after accounting for leave, sickness, and training. The value of .75 is an adjustment for the workload randomness. Air Force Regulation (AFR) 173-13 contains the necessary acquisition and training costs figures for various categories of enlisted and officer personnel (AFR). The acquisition cost for airmen was 3200 dollars in fiscal year 1985, training costs were 7767 dollars and the turnover rate was .120 (14:116). The CER for personnel acquisition and training is C_{13k}, the maintenance man hours were derived from components of equations C_{2k}, C_{6k}, C_{7k}, and C_{8k} from the LCC-2 user's guide (22:Ch 2, 15,16,23,24,27-29).

$$C_{13k} = .120 \times (3200+7767) \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \qquad (25)$$

where

$$\text{Maintenance Man Hours} = \left(RLS_1 \times \sum_{m=1}^{12} \frac{NCUM_{km}\ NQ_1\ OH\ RTS_1}{G_{km}\ MTBF_1} \right)$$

$$+ \left(\sum_{i \in I_1} ENR_{ik} \times RRS_i \right) + \sum_i \left(\delta(LV_i=1) \times ENR_{ik} \times FVS_i + \right.$$

$$\left. + \delta(LREM=1) \times ENR_{ik} \times RRS_i \right) + \delta(k > WP) \times \sum_i ENR_{ik}$$

$$\times \left(\delta(k \leq ISP) \ \delta(LVi=2) \times FVSi + (1-UFPi) \times NRTS_i \times RLS_i \right.$$

$$+ \delta(LREM_i=2) \times RRS_i \quad + \delta(k \geq ISP) \times \delta(LV_i=2) \times FVS_i$$

$$+ (1-UFP_i) \times NRTS_i \times RLS_i + \delta(LREM_i=2) \times RRS_i \Big)$$

Permanent Change of Station (PCS) Costs. The CER for the PCS cost element was determined in the same manner as the previous personnel acquisition and training CER. AFR 173-13 contains a PCS cost per work year of 451 dollars for fiscal year 1985 enlisted personnel (14:41). The same assumption concerning the employment of only enlisted personnel for maintenance was adopted. Therefore, C_{14k}, the CER for the PCS cost element is listed below.

$$C_{14k} = 451 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \tag{26}$$

Miscellaneous O&M. Miscellaneous O&M costs are addressed by C_{15k}.

$$C_{15k} = 5030 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \tag{27}$$

This element applies to both military and civilian employees and "includes such items as TDY travel, utilities, purchased services, and office supplies" (29:Ch 15, 3). The value for miscellaneous O&M costs per person in 1985 was $5030 (14:115).

Medical O&M Non-Pay. C_{16k}, Medical O&M Non-Pay costs, covers the "wages for doctors, nurses and other medical personnel, the government incurs the cost of medical supplies and for such programs as CHAMPUS for each military person" (29:Ch 15, 3). Again, as with several other CERs which address new cost elements created by the CAIG standard cost element structure, the assumption is made that only enlisted personnel are utilized. This allows the use of AFR 173-13 figures concerning the average cost per man for costs like acquisition, training, and PCS. AFR 173-13 provides standard factors that distinguish between officer and enlisted, currently both categories are equal to $758 in fiscal year 1985 dollars (14:116).

$$C_{16k} = 758 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \qquad (28)$$

Maintenance Material. Maintenance material is

> the cost of expense material used in unit level maintenance. This includes non-reparable items that are not centrally managed with individual item reporting. Excludes reparables procured from the stock fund which are included in cost elements for replenishment spares [29:Appd A, 19].

May notes that "maintenance material costs are commonly called Base Maintenance Supplies (BMS) in the Air Force" (29:Ch 12, 1). Additionally BMS are broken down into two categories, general and system.

> General BMS consists of those items managed and procured by the Defense Logistic Agency or the General Services Administration. They are normally non-critical items, especially those common to more than one service. System BMS constitute the remainder of the material items and repair parts managed and procured by the MAJCOM or AFLC [29:Ch 12, 1].

May writes:

> Historically, this has been an area of low analytical effort due both to the low percentage contribution it typically makes to total O&S costs and the poor quality of the data base... Developing an adequate

data base has been a problem due to the fact that a large portion of these items are issued to work center bench stocks rather than directly to weapon systems [29:Ch 12, 1].

VAMOSC currently outputs a value for BMS by mission design series (MDS), however, no further breakdown is available. When the figures are examined, values under five percent of annual O&S costs are normally observed (29:Ch 12, 1). Assuming that BMS costs are equally distributed between the subsystems of an air frame there would be justification for utilizing a CER which consisted of taking five percent of the annual LCC.

According to Mr. Conway of the Aeronautical Systems Division's Life Cycle Cost division (ASD/ALTB) the LCC analysts use a figure of approximately five percent when no better information is available based on similar systems. For the purpose of the model a default value of five percent will be used unless the analyst has better information available. The CER for BMS will be C_{17k}.

$$C_{17k} = PBMS_k \sum_{i=1}^{16} C_{ik} \qquad (29)$$

where C_{ik} = The value of a CER i in year k.

$PBMS_k$ = Percentage of base maintenance supply costs to total annual LCC in year k.

V. Applications Analysis

This chapter will demonstrate the modified LCC-2 model by applying some real world data and performing the calculations necessary to arrive at outputs for the various cost estimating relationships. The calculations will be performed for one representative year, year ten. The data is for the F-111 digital flight control system. Due to the complexities involved in calculating the values of:

D_{im} = Demand rate in demands per hour for spares of unit i at base m,

D_i = Demand rate in demands per hour of unit i on the depot spares supply,

T_{im} = Average stock replenishment time in hours for spares of unit i at base m,

T_i = Depot stock replenishment time in hours for unit i

EBO_{lm} = Expected LRU backorders at base m,

$$= \sum_{i \in I_l} \sum_{x=n_{im}+1}^{\infty} (x-n_{im}) \frac{(D_{im}\ T_{im})^x}{x!} e^{-D_{im}\ T_{im}}$$

EBO_{sm} = Expected SRU backorders at base m,

$$= \sum_{i \in I_s} \delta(LREM_i=1) \sum_{x=n_{im}+1}^{\infty} (x-n_{im}) \frac{(D_{im}\ T_{im})^x}{x!} e^{-D_{im}\ T_{im}}$$

the non modified LCC-2 model software was employed to calculate these intermediate values when needed. The intermediate values are employed in the calculation of C_{19k}, the initial support spares. The remainder of the CER's were more straight-forward to calculate. Each cost element of the CAIG standard cost element will be addressed and the appropriate CER(s) for the cost element presented. Actual calculations are shown in Appendix F.

Unit Mission Personnel

In the unit mission personnel cost element, only maintenance personnel were considered applicable to this modeling effort. This model was intended for use with avionics or similar subsystems for DOD weapons systems. Personnel are normally assigned and accounted for at the mission design series (MDS) level. Additionally, it was felt that when comparing two alternative systems only the differential costs are important and the difference in aircrew and other personnel required for support of either system would be negligible. The value for maintenance personnel costs, which is derived from the maintenance hours of flight line and base level mission personnel, could differ significantly based on the reliability and maintainability of the alternative weapon subsystems. The unit mission maintenance personnel costs are computed by summing the components C_{2k} and C_{3k}.

Unit Level Consumption

When considering avionics and similar subsystems, we can ignore petroleum, oil, and lubricants (POL) and training ordnance. The remaining element of maintenance material is addressed by C_{17k}. The calculation of the value for year ten is found in Appendix F.

Depot Level Maintenance

Under depot level maintenance two non applicable elements are found. Airframe rework, and engine rework are not applicable to avionics systems or similar subsystems. Other depot maintenance, is a cost element utilized for unusual depot maintenance and therefore normally considered to be zero. Component repair is taken into account by C_{4k}, depot level maintenance. Support equipment rework is covered by C_{8k}, support equipment maintenance. C_{9k}, software maintenance cost, is a new CER to address the cost of software maintenance over the operating life of the system. The CER is derived from the COCOMO model (4). Modification labor, C_{10k}, is a new CER also. This CER is intended to estimate the cost of modifications performed at the depot level. The final element under depot level maintenance is contracted unit level support. This element is covered by C_{12k}. Representative calculations for C_{4k}, C_{8k}, C_{9k}, C_{10k}, and C_{12k} are shown in Appendix F.

Personnel Acquisition and Training

The cost of personnel acquisition and training was not addressed by the LCC-2 model. This modification of the model has included C_{13k}, personnel acquisition and training cost in order to comply with the CAIG standard. The assumption that all maintenance was performed by enlisted personnel was applied. This assumption is probably valid at the lower maintenance levels but more suspect as you reach the depot level. Representative calculations are shown in Appendix F.

Sustaining Investment

The element of "other recurring investments" is similar to the depot level's "other depot maintenance" element. It is intended to account for all sustaining investments which are not for spares, support equipment, or modification kits. Therefore, in this model we have considered it to be zero. Replenishment spares are addressed by C_{1k}, the spares cost to estimate the cost of condemnation spares over the operating life of the system. Replacement support equipment is not addressed by this model. Only the maintenance and spares necessary to keep the initial support equipment operational is considered. C_{11k} is a new CER to address the cost element for modification kits.

Installation Support Personnel

The costs for installation support personnel were considered to be non-applicable to this model based upon the same reasoning as for unit mission aircrew and other personnel. The standard method accounts for these personnel at the major weapons system level by MDS and personnel are not broken out by subsystems. Also, as noted previously, when comparing alternative weapon systems the differences in numbers of mission, base support, and indirect support personnel are negligible. Therefore, they need not be considered.

Indirect Personnel Support

This cost area contains four elements three of which are addressed by the modified model, and one which is not applicable to the Air Force, but is included to maintain standardization within the branches of the DOD. The PCS costs are summed up by C_{14k}. Miscellaneous O&M costs are addressed by C_{15k}. These costs are for TDY travel, utilities, purchased services, and office supplies. C_{16k} covers Medical O&M Non-Pay costs. This CER accumulates the costs of medical supplies, CHAMPUS, doctors and other medical personnel wages.

Depot Non-Maintenance

The depot non-maintenance category is "to account for the marginal cost to general depot support activities and to second destination transportation resulting from fielding a new weapon system" (29:Ch 15, 4).

General Depot Support. The cost element of general depot support is covered by two CERs, C_{5k} and C_{6k}. C_{5k} sums up the item management costs of the system. C_{6k} accumulates the data management costs of the system.

Second Destination Transportation. The packaging and shipping costs are combined under this element of the depot non-maintenance category. The CER which computes these costs is C_{7k}, packaging and shipping in year k.

VI. Conclusions and Recommendations

The purpose of this thesis research was to modify the LCC-2 avionics life cycle cost model to comply with the standardized CAIG aircraft cost element structure. To accomplish the objective of the thesis the answers to four questions were necessary. First, what is the CAIG standard cost element structure for aircraft systems. This question was answered through an extensive literature review. The literature reviewed included books, magazines, regulations, written correspondence and memoranda. In addition to the review of written material several discussions were held with various LCC analysts and experts.

The second question asked what cost element structure was the LCC-2 model constructed around. Again, the question was answered through the literature review. Specifically, the review of the LCC-2 model user's guide and discussions with Mr. John Huff and Lt. Larry Fifer.

The third question concerned the specific cost estimating relationships utilized by the LCC-2 model to yield the cost elements of the cost element structure. The modification of these cost estimating relationships to reflect the new cost elements of the CAIG approved standard aircraft system's cost element structure was necessary. What are the specific cost estimating relationships of the LCC-2 model? This question also was addressed through the literature review.

Finally, procedures for modifying the specific LCC-2 cost estimating relationships to yield the CAIG approved standard cost elements is needed. This problem was handled through the knowledge gained from answering the first three questions. Additional cost estimating relationships were formulated to cover cost elements not previously addressed by the LCC-2 model. Ideas for these cost estimating relationships and decisions regarding their degree of detail were aided by reviewing other LCC models, literature, and by personal and phone interviews with experts in the area of LCC.

This research effort was successful in modifying the LCC-2 cost element structure into the CAIG standard aircraft system's cost element structure. This will enable LCC analysts to again utilize the model for weapon system comparisons following the recoding of the software.

Additionally the model now addresses several new areas of costs, the most significant one being software maintenance costs. These new cost areas were included to maintain compliance with the CAIG standard cost element structure, which will aid in the valid comparison of alternative weapon systems.

Recommendations

It is recommended that the cost estimating relationships in this thesis be software coded utilizing a modular top down programming approach. Various outputs from these cost estimating relationships would be necessary. One output option from these relationships should be formated in a tabular form with headings from Table 2, the CAIG cost elements. Values for each heading by year should be output. A table showing the total LCC for each cost element over the total proposed life cycle and a grand total of all LCC should be a second output. Additional outputs similar in format to the LCC-2 model's outputs one through five should be provided. Documentation should be incorporated in the code as well as the user's guide to aid in future modifications.

The purpose of this research was to modify the LCC-2 model to comply with the CAIG standard cost element structure for aircraft systems. All models used to compare alternative weapon systems must comply to that standard. Due to the inadequacies, or in some cases, the total absence of databases concerning several cost elements, very crude estimates were used to provide outputs. The amount of effort expended on formulating cost estimating relationships in the areas with inadequate or no databases was moderated by the percentage of total annual LCC these areas probably contributed. However, as the budget in the DOD becomes tighter, greater accuracy will be required in all the various cost elements which compose the weapon system's total LCC. Therefore, a second recommendation is to review the current databases with the intent of modifying or possibly creating new databases where the collection of the necessary data would be cost effective.

Areas for Future Research

Specifically, data is desperately needed concerning the amount of annual change in software lines of code, the annual change traffic (ACT) variable of the COCOMO model. Software maintenance costs have risen at a rapid rate as a result of extensive computerization in avionics, communications, and other related areas. Due to the amount of money spent on software maintenance, efforts to achieve better estimates for this cost element may pay for themselves. Another area for future research includes base maintenance supplies (BMS), which currently can only be estimated down to the MDS level.

The software coding of this model as suggested in the recommendations would be a possible follow on thesis for a perservering programmer. Starting from scratch is suggested as the current coding is difficult to follow and modify due to interactions between modules.

Conclusion

The DOD has realized that uncontrolled growth of O&S costs will cripple and eventually eliminate funding for future research, development and acquisition of weapon systems. Therefore, O&S cost control was and is given a large degree of attention. LCC models were rapidly generated to fill the need for calculation of LCC and the comparison of alternative weapon systems. In time, one of the deficiencies, which seems inherent with many such rapid and dynamic growths, became apparent. There was a lack of standards upon which these models were based. This resulted in a diminished ability to compare one system against another, which was a prime reason for the development of LCC models. The formation of CAIG brought standardization to the area of LCC, particularly the O&S component of LCC. This standardization was needed to achieve comparability and validity in weapon systems acquisition.

This standardization forced the modification or discontinuance of old models. The LCC-2 model was an unmodified model which was used effectively for the estimation of avionics LCC. The model was effective in estimating the LCC of avionics systems, but fell into disuse for DSARC (now JRMB) decisions due to its non-standard cost element structure. This thesis effort has modified the LCC-2 cost estimating relationships to reflect the CAIG standard aircraft system cost element structure.

Appendix A. Glossary of Symbols

Note: Unless denoted by an @ all symbols and definitions are from the LCC-2 user's guide (22: Appd A).

AO_l - LRU availability objective (the steady-state probability that an LRU is not in an unrepairable state at base level due to a backorder on the SRU spare supply)

AO_s - System availability objective (the steady-state probability that an aircraft is not in NORS (not Operationally Ready due to Supply)

AO1 - Spares objective (system)

AO2 - Spares objective (shop)

BDSA - Average shipping time in hours from base to depot

BDSC - Average shipping time in hours to depot from CONUS bases

BDSO - Average shipping time in hours to depot from overseas bases

BTC - Base training cost in dollars

C_k - Total cost in dollars incurred by the government in year k

C_{ik} - Value in dollars of LCC element i incurred in year k

CDMC - Contractor depot repair cycle time in hours

$CMOD_{jk}$@ - The cost of a type j modification kit in year k

COM_j - Annual cost to operate and maintain a set of support equipment item j, expressed as a fraction of the acquisition cost

$COND_i$ - Expected fraction of unit i failures resulting in unit condemnation

CPS_i - The average shipping cost in dollars per shipment of unit i

$CRSC$ - Resupply time in hours from contractor facility to CONUS bases

$CRSO$ - Resupply time in hours from contractor facility to overseas bases

CRU_i - Cost in dollars per unit for spare of unit i

CSC@ - Cost of support contract

CSE_j - Unit cost in dollars for support equipment line item j

D_i - Demand rate in demands per hour of unit i on the depot spare supply

D_{im} - Demand rate in demands per hour for spares of unit i at base m

DCB - Base repair technical orders cost in dollars

DCD - Depot repair technical orders cost in dollars

DCO - Operation technical orders cost in dollars

DF - Annual discount factor applied to future costs

DMC - Depot repair cycle time in hours for units which can be repaired by removal and replacement operations (RTS type repairs)

DRC - Depot repair cycle time in hours for units which require actions more complex than removal and replacement operations (NRTS repairs)

DSSF - Depot stock safety factor in standard deviations

DTC - Depot training cost in dollars

EBD_{im} - Expected delay in hours for repair of LRU i at base m due to stockout of spare SRU

EBD_{ijm} - Expected delay in hours for repair of LRU i at base m due to stockout of SRU j

EBO_{lm} - Expected LRU backorders at base m

EBO_{sm} - Expected SRU backorders at base m

EDD_i - Expected delay in hours in RTS repair of LRU i due to stockout of spare SRUs

EDD_{ij} - Expected depot delay in hours in RTS repair of LRU i due to stockout of SRU j

ENR_{ik} - Expected number of removals of unit i in year k

ESD_i - Expected resupply time delay in hours due to depot stockout of unit i

FVS_i - Labor standard in hours for failure verification of unit i

G_k - Ratio of the projected system Mean Time Between Failures (MTBF) in year k to the initial MTBF

G_{km} - Ratio of the projected system MTBF in month m of year k to the initial system MTBF

G^* - Ratio of the projected system MTBF at the time of full installation to the initial system MTBF

$HMOD_{jk}$@ - Number of hours required to perform the type j modification in year k

I_l - Set of indices pertaining to LRUs

I_s - Set of indices pertaining to SRUs

ISITE - Number of I level sites at which aircraft using the system are deployed

ISP - Initial support period (years)

$ISYS_m$ - Number of I level systems to be installed at site m

i^* - Index of the unit which provides the greatest reduction in expected backorders in a particular iteration of the base level spares determination algorithm

J_b - Set of indices pertaining to line items of support equipment required at base level

J_d - Set of indices pertaining to line items of support equipment required at depot level

J_i - Set of indices pertaining to SRUs contained in LRU i

KDSI@ - Number of lines of software code in thousands

LR_i - Maintenance level of repair (initial support period) for unit i: LR_i =0 (flight line); =1 (base); =2 (depot)

$LR2_i$ - Maintenance level of repair (final support period) for unit i: $LR2_i$ =0 (flight line); =1 (base); =2 (depot)

$LREM_i$ - Maintenance level of removal for unit i: $LREM_i$ =0 (flight line); =1 (base); =2 (depot)

LV_i - Maintenance level of failure verification (initial support period) for unit i: LV_i =0 (flight line); =1 (base); =2 (depot)

$LV2_i$ - Maintenance level of failure verification (final support period) for unit i: $LV2_i$ =0 (flight line); =1 (base); =2 (depot)

$MTBF_i$ - Mean Time Between Failures of unit i in hours

n_j - Number of sets of support equipment item j required at depot

n_{im} - Current spares level of unit i at base m in a particular iteration of the base level spares determination algorithm

NAC_k - Number of systems installed in year k

NBASE - Total number of bases at which aircraft using the system are deployed

NBC - Number of bases - CONUS

NBO - Number of bases - overseas

NCS_i - Number of condemnation spares of unit i

$NCUM_{km}$ - Cumulative number of systems installed by month m of year k

NDS - Number of depot work shifts

NI - Number of new items (no Federal Stock Number assigned) in the proposed design which must be stocked by the government to support system maintenance

NIC - Number of I level sites CONUS

NIO - Number of I level sites overseas

NIS - Number of I level work shifts

$NMOD_{jk}$@ - Number of type j modifications in year k

NPB - Number of pages of base repair technical orders

NPD - Number of pages of depot repair technical orders

NPO - Number of pages of operation technical orders

NQ_i - Quantity of unit i required per system

$NREQ_{jk}$ - Number of sets of support equipment item j required in year k

NRS_i - Total number of initial spares required for unit i

$NRSB_{im}$ - Number of spares of unit i required at base m

$NRSD_i$ - Number of spares of unit i required at the depot

NRU - Number of replaceable units in the system hardware configuration (counting the system itself)

$NRTS_i$ - Expected fraction of failures of unit i that are reparable only at depot

NS_c - Total number of systems to be installed on aircraft at CONUS bases

NS_o - Total number of systems to be installed at overseas bases

NSE - Number of unique line items of support equipment

$NSYS_m$ - Total number of systems to be installed at base m

NTOT - Total number of systems to be installed

NY - Operational life of the system in years

OH - Average operating hours peer month per installed system

$PBMS_k$@ - Percentage of base maintenance supply costs to total annual LCC in year k

$RBHPM_{j,m}$ - The expected hours per month that support equipment item j is required at base m

$RHPM_j$ - Expected hours per month that support equipment item j is required at depot

RLS_1 - Average labor in manhours per in-place system repair

RLS_i - Average labor in manhours per NRTS repair of unit i

RMS_1 - Average materials cost in dollars per in-place system repair

RMS_i - Average materials cost in dollars per NRTS repair of unit i

RRS_i - Average labor in manhours required to isolate a failure to unit i, remove the unit, replace it with a spare, and verify the corrective action

RST_m - Resupply time in hours to base m

RSTC - Resupply time in hours between the depot and CONUS bases

RSTO - Resupply time in hours between the depot and overseas bases

RTS_1 - Expected fraction of system failures that are reparable in-place

RTS_i - Expected fraction of failures of unit i that are reparable by removal and replacement operations

SBMC - Consumable materials consumption rate in dollars per manhour at base level

SBR - Standard base labor rate in dollars per manhour

SCP@ - Support contract period in years

SDC2 - Consumable materials consumption rate in dollars per manhour at depot level for final support period

SDM - Standard data management cost in dollars per page per year

SDMC - Consumable materials consumption rate in dollars per manhour at depot level for initial support period

SDR - Standard depot labor rate in dollars per manhour for initial support period

SDR2 - Standard depot labor rate in dollars per manhour for final support period

SID - Standard cost in dollars per copy per page for reproduction and distribution of technical data

SIE - Standard cost in dollars per item for entering a new item into the government supply system

SIM - Standard inventory management cost in dollars per year

SIN - Installation cost in dollars per system

SPSC - Standard cost in dollars per pound for packaging and shipping units between the depot and overseas bases

SPSO - Standard cost in dollars per pound for packaging and shipping units between the depot and overseas bases

T_i - Depot stock replenishment time in hours for unit i

T_{im} - Stock replenishment time in hours for unit i at base m

TAT - Base turnaround time in hours

$TOTCOS_{pv}$ - Total life cycle cost for the system in present value dollars

$TOTCOS_u$ - Total life cycle cost for the system in undiscounted dollars

UFP_i - Expected fraction of removals of unit i that will be unverified failures (RTOKs)

$USER_{ij}$ - Support equipment item j usage time in hours for repair of unit i

$USEV_{ij}$ - Support equipment item j usage time in hours for verification of unit i

W_i - Weight in pounds for unit i

WHPM - Working hours per month at the depot

WHPS - Working hours per month at the site

WP - Warranty period in years

WPR - Price of the warranty in dollars

Λ_{im} - A variable in the base level spares determination algorithm denoting the reduction in expected backorders at base m achieved by increasing the current spares level of unit i at base m by one

δ(statement) - A variable whose value is 1 if the statement is true and 0 otherwise

Appendix B. Description of O&S CERs

$$C_{1k} = \frac{NAC_k}{NTOT} \times \left(\sum_{i \in I_L} NCS_i \times CRU_i \right) + \delta(k=WP+1)$$

$$\times \sum_{j=1}^{k} \frac{NAC_j}{NTOT} \times \left(\sum_{i \in I_S} NCS_i \times CRU_i \right) + \delta(k \geq WP+1)$$

$$\times \left(\frac{NAC_k}{NTOT} \right) \times \sum_{i \in I_S} NCS_i \times CRU_i \qquad (1)$$

This is equation (1) and is a subset of the LCC-2 C_{2k} equation which combined production or initial spares with condemnation spares. The original equation was in three parts. Part one estimated the LRU spares for any given year. Part two estimated the SRU spares during the warranty period and part three covered the period after warranty expiration. Each of these parts estimated both initial and condemnation spares together. To comply with the CAIG guidance it was necessary to separate the two types of spares, initial and condemnation, yielding acquisition and O&S cost elements respectively. Equation C_{1k} represents the cost for O&S condemnation spares in the year k. The three part breakdown is retained to give greater definition to the type of spares, LRU or SRU.

The calculation of condemnation spares NCS_i involves the intermediate calculation on ENR_{ik}, the expected number of removals of unit i in year k. This intermediate calculation is described in the LCC-2 users guide in Chapter 2 on pages 23 and 24 . These two equations are shown below (22:Ch 2, 23-4).

$$ENR_{ik} = \sum_{m=1}^{12} \frac{NCUM_{km} \times OH \times NQ_i}{(1-UFP_i) \times G_{km} \times MTBF_i} \qquad (30)$$

$$NCS_i = \sum_{k=1}^{NY} ENR_{ik} \times (1-UFP_i) \times COND_i \qquad (31)$$

The following equation (2), for C_{2k}, generates the flight line component of the unit mission personnel maintenance cost element.

$$C_{2k} = \left[RLS_1 \times \sum_{m=1}^{12} \frac{NCUM_{km} \times NQ_1 \times OH \times RTS_1}{G_{km} \times MTBF_1} + \sum_{i \in I_1} ENR_{ik} \times RRS_i \right] \times \left[\frac{24309}{12 \times 144 \times .75} \right] \qquad (2)$$

This equation utilizes the approach of the LCC-2 equation C_{6k} to determine the number of flight line maintenance hours. Basically, the first term determines the amount of labor to perform in place repair of a system and the second term calculates the time involved in isolating the failure to a particular LRU and removing and replacing it. This equation contains only O&S costs. Having the total flight line maintenance hours on a particular system, an equivalent number of maintenance man years to support the system can be determined. These maintenance man years are subsequently converted to dollars. The determination of the equivalent man years is adjusted for factors such as leave, sickness, training, and TDY as suggested by May (29:Ch 7, 7). The final equivalent maintenance man years is converted into dollars by multiplying it by the average military pay rate for total enlisted force worldwide (14:40).

Equation (3), for computing C_{3k}, generates the base level component of the unit mission personnel maintenance cost element. This equation employs the logic of the C_{7k} equation from the LCC-2 user's guide to yield the total base level maintenance hours for a system (22:Ch 2, 28).

$$C_{3k} = \left(\sum_i \delta(LV_i = 1) \times ENR_{ik} \times FVS_i + \delta(LREM_i = 1) \times ENR_{ik} \times RRS_i \right) \times \left(\frac{24309}{12 \times 144 \times .75} \right) \qquad (3)$$

The equation sums the costs for labor employed to ascertain the condition of an LRU and/or repair it at base level. The first term of the equation determines the hours of labor to verify a failure in a particular LRU. The use of the (LV_i=1) signifies that the work was done at base level. The second term accumulates the hours for labor to isolate the failure, remove and replace the LRU, and check the replacement unit. These maintenance hours are equated to equivalent man years and adjusted as above in equation (2). The adjusted equivalent man years are then converted into dollars as above in equation (2) by applying the appropriate pay rate plus allowances from AFR 173-13 (14:40).

Equation (4) addresses only O&S costs and is identical to the LCC-2 equation C_{8k} (22:Ch 2, 29).

$$C_{4k} = \delta(k > WP) \times \sum_i ENR_{ik} \Big[\delta(k \leq ISP) \Big(\delta(LV_i = 2) \times FVS_i \times SDR + (1 - UFP_i) \times NRTS_i \times \big(RLS_i \times SDR + SDMC + RMS_i\big) + \delta(LREM_i = 2) \times RRS_i \times (SDR + SDMC)\Big) + \delta(k > ISP)\Big(\delta(LV_i = 2) \times FVS_i \times SDR2 + (1 - UFP_i) \times NRTS_i \times \big(RLS_i \times SDR2 + SDC2 + RMS_i\big) + \delta(LREM_i = 2) \times RRS_i \times (SDR2 + SDC2)\Big)\Big] \quad (4)$$

The equation estimates depot maintenance costs. It allows for the use of two depot maintenance rates during the life cycle of the system. The equation has two main parts $\delta(k \leq ISP)$ and $\delta(k > ISP)$ which estimate the costs in the initial support period and the follow on period respectively. Within each of these parts identical calculations are performed to determine the labor to verify a failure, and the cost of labor and materials to fix a unit i which is not reparable at base level. Once this is done for each particular unit i for a specified year, the expected number of failures for that unit in the specified year is applied to yield a total dollar cost for each unit i category. in the year k.

Equation (5) computes C_{5k}, the cost of inventory management in the year k.

$$C_{5k} = \delta(k > WP) \times NI \times SIM \quad (5)$$

This is an O&S cost element. The equation accumulates a standard annual inventory management cost each year for each item in the inventory.

Equation (6) estimates the O&S cost involved with file maintenance of technical data collected during the life cycle of a system.

$$C_{6k} = (NPB + NPO) \times SDM + \delta(k > WP) \times NPD \times SDM \qquad (6)$$

The first term computes the cost for base repair and operation technical orders based on the number of pages and a standard rate per page. The second term calculates the cost of depot repair technical orders following the warranty period, if one exists, based on the number of pages and the standard rate per page.

Equation (7) determines C_{7k}, the packaging and shipping cost in year k. Prior to computing C_{7k} an intermediate value CPS_i must be calculated. The equation and relevant variables for CPS_i below are from the LCC-2 users guide (22:Ch 2, 33-4)

$$CPS_i = W_i \times \frac{NS_c}{NTOT} \times SPSC + \frac{NS_o}{NTOT} \times SPSO \qquad (32)$$

where

W_i	=	weight of unit i in pounds
NS_c	=	Total number of systems to be installed on aircraft at CONUS bases
NS_o	=	Total number of systems to be installed on aircraft at overseas bases
NTOT	=	Total number of systems to be installed
SPSC	=	Standard cost in dollars per pound for packaging and shipping units between the depot and CONUS bases
SPSO	=	Standard cost in dollars per pound for packaging and shipping units between the depot and overseas bases (22:Ch 2, 33-4).

$$C_{7k} = \sum_i \delta(LREM_i \leq 1) \times CPS_i \times ENR_{ik} \times (1-UFP_i)$$

$$\times \Big(2 \times NRTS_i + COND_i + \delta(LR_i=2) \times 2 \times RTS_i$$

$$+ \delta(LV_i=2) \times 2 \times \frac{UFP_i}{1 - UFP_i} + \delta(LV_i=2) \times COND_i\Big) \qquad (7)$$

Equation (7) looks at each particular unit in year k and determines the fraction of those units which must be shipped to and from the depot, (round trip), and the fraction shipped only one way. The two ways are composed of units repairable only at depot, and units retested okay (RTOKs) at the depot. Units condemned at the depot require only shipment to the depot. The sum of these terms is then multiplied by the expected number of removals of the particular unit, and the fraction of that particular unit that is removed at base level and below and sent to depot. This will yield the total number of shipments of unit i, which is then multiplied by the average one way shipping cost of unit i, CPS_i. The summation of these costs for each type of unit i in year k yields C_{7k}.

Equation (8), C_{8k}, generates the support equipment maintenance costs.

$$C8k = \sum_{j=1}^{NSE} NREQ_{jk} \times CSEj \times COMj \qquad (8)$$

The equation determines the cost of all requiied pieces of support equipment. First the required number of a particular type j support equipment item is multiplied by the cost of that type j equipment to yield the total cost of all the type j support equipment. Next, the total cost of all type j support equipment is multiplied by an adjustment factor, COM_j. COM_j estimates maintenance cost as a percentage of the total support equipment acquisition costs. This generates the value of support equipment maintenance for the particular type j piece of support equipment. To obtain the total for all types of support equipment, the above process must be applied to the remaining types of support equipment.

Appendix C. Description of Production CERs

This appendix will discuss the production cost estimating equations in greater detail than Chapter 4 of the thesis. The cost estimating relationships and any supporting intermediate calculations will be addressed in numerical order according to their C_{ik} designator. The equation number from the text is included for reference in parentheses in the right margin of the CER.

$$C_{18k} = NAC_k \times ACS \tag{9}$$

C_{18k} computes the hardware acquisition cost by multiplying the number of systems installed in year k, NAC_k, by the acquisition cost per system in dollars, ACS.

$$\begin{aligned} C_{19k} = {} & \frac{NAC_k}{NTOT} \times \sum_{i \in I_1} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right) \\ & + \delta(k = WP+1) \times \sum_{j=1}^{k} \frac{NAC_j}{NTOT} \sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} \right. \\ & \left. + NRSD_i \times CRU_i \right) + \delta(k > WP+1) \times \frac{NAC_k}{NTOT} \\ & \sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right) \end{aligned} \tag{10}$$

C_{19k} totals the initial spares cost for the system in year k. C_{19k} is a subset of the LCC-2 equation C_{2k} (22:Ch 2, 15-6). The equation C_{19k} consists of three main parts. The first part computes the number of a specific LRU needed at each base and depot and multiplies this number by the cost per unit, CRU_i. This is done for each particular unit i which is a LRU to yield the total cost for all spares at the bases and depots. This value is then adjusted by the percentage of systems installed in year k to yield the total cost of LRU spares in year k. The second part is similar to the first part except that SRUs are addressed which are needed prior to the expiration of a warranty, if a warranty exists. When a warranty exists, the entire cost for the spares in the contract period is accumulated at the end of the warranty period. The third term computes the number of initial spares needed to field systems installed after the expiration of the warranty period, if one exists. Again, the calculation follows the approach setup for part one.

There are two intermediate values which must be determined prior to C_{19k}. These values are $NRSB_{im}$ and $NRSD_i$, the number of spares of unit i required at base m and the number of spares of unit i required at the depot. The calculation of these values is dependent on several variables and a procedure is outlined in the LCC-2 user's guide for their determination by a computer algorithm (22:Ch 2, 17-23).

C_{20k} determines the cost for initial support equipment. The equation consists of three parts and is identical to the LCC-2 equation C_{3k} (22:Ch 2, 24-6). The first part computes the cost of support equipment needed at each base by multiplying the required number of a particular support equipment item buy the cost per item. This is accomplished for each type of support equipment at each base and then adjusted to take into account the percentage of total systems installed that

$$C_{20k} = \delta(k \geq ISP) \frac{NAC_k}{NTOT} \times \sum_{j \in J_b} \sum_{m=1}^{ISITE} CSE_j \times n_{jm}$$

$$+ \delta(k{=}WP{+}1) \times \left(\sum_{i=1}^{k} \frac{NAC_i}{NTOT} \right) \times \left(\sum_{j \in J_d} n_j \times CSE_j \right)$$

$$+ \delta(k > WP{+}1) \times \left(\frac{NAC_k}{NTOT} \right) \times \left(\sum_{j \in J_d} n_j \times CSEj \right) \qquad (11)$$

year. The calculation of the first part of C_{20k} is for the period following the initial support period, if one exists. The remaining two parts address the depot level support equipment for the time up to and including the warranty expiration and the period following warranty expiration, if a warranty existed. The intermediate value of $n_{j,m}$, the number of sets of support equipment item j required for each I level site m, is found in the LCC-2 user's guide addendum Chapter 2 pages three and four (22:Addm 2, 3-4).

$$C_{21k} = NAC_k \times SIN \qquad (12)$$

C_{21k} determines the system installation cost. The cost is computed by multiplying the number of systems installed in year k by the cost per system installation.

$$C_{22k} = \delta(WP > 0) \times \frac{NAC_k}{NTOT} \times WPR \qquad (13)$$

C_{22k} computes the cost for a warranty employed for system support. The equation prorates the warranty cost for each year based on the percentage of systems installed in the year k to the total number of systems to be installed.

$$C_{23k} = \delta(k=1) \times BTC + \delta(k=WP+1) \times DTC \qquad (14)$$

Initial training costs are accumulated under C_{23k}. These costs are charged the first year of the program for both base and depot level, unless a warranty is employed at depot level. The depot training cost is then charged following the warranty expiration.

$$C_{24k} = \delta(k=1) \times (DCB + DCO) + \delta(k=WP+1) \times DCD \qquad (15)$$

C_{24k} estimates the costs involved in obtaining operation and repair manuals for the system. As with the initial training costs above, the costs are charged in the first year except for the case where a warranty is used at the depot level.

$$C_{25k} = \delta(k=WP+1) \times NI \times SIE \qquad (16)$$

The initial item management costs are computed with C_{25k}. The equation multiplies the number of new items by the standard cost per item to enter a new item. When a warranty is involved the cost is charged following the expiration of the warranty.

$$C_{26k} = \delta(k=1) \times SID \times (2 \times NPB \times NBASE + NTOT \times NPO)$$
$$\delta(k=WP+1) \times 5 \times NPD \times SID \qquad (17)$$

The initial data management costs are determined by C_{26k}. The equation contains two terms. The first term accounts for the cost of base repair technical orders. The second term sums up the depot cost and takes into account that the cost may not be charged until after warranty expiration, if a warranty is employed. Each term involves the determination of the total number of pages and then multiplies by the standard cost per page for reproduction and distribution.

Appendix D. F-111 Digital Flight Control System Data

Note: All variables names listed below are from the LCC-2 user's guide unless denoted by an @ (22:Appd A). The data values listed are from ASD/YYLM and provided through Lt. Larry Fifer (19). Only values for the first two items, one LRU and one SRU are shown. The value for the LRU will be listed first.

ACS - 422,629.00

AO_l - .99

AO_s - .99

AO1 - .99

AO2 - .99

BDSC - 504

BDSO - 756

BTC - 0

CDMC - 538

$CMOD_{jk}$@ - 3,000 (This value was arbitrarily chosen so that calculations could be demonstrated.)

COM_j - .08

CRU_i - 97652, 4439

CSC@ - 2,000,000 (This value was arbitrarily chosen so that calculations could be performed.)

CRSC - 50

CRSO - 384

CSE_j - 657,571.00

DCB - 153,225.00

DCD - 170,250.00

DCO - 51,075.00

DF - .10

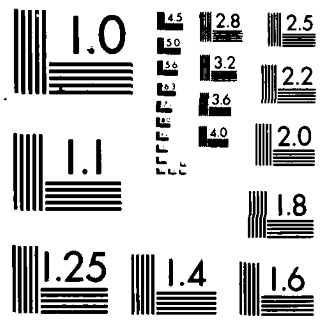
DMC	- 912	
DRC	- 912	
DSSF	- 1.65	
DTC	- 250,000.00	
FVS_i	- .5, 2	
G_k	- 1.0	
G_{km}	- 1.0	
G^*	- 1.0	
$HMCD_{jk}$@	- 5	(This value was arbitrarily chosen to allow calculations to be demonstrated.)
ISP	- 4	
KDSI@	- 50	
LR_i	- 1, 2	
LV_i	- 1, 2	
$MTBF_i$	- 1750, 22750	
$MTBF_1$	- 854	
NBASE	- 6	
NBC	- 4	
NBO	- 2	
NDS	- 2	
NI	- 75	
NIC	- 4	
NIO	- 2	
NIS	- 2	
$NMCD_{jk}$@	- 50	(This value was arbitrarily chosen to allow calculations to be performed.)
NPB	- 10	
NPD	- 225	

NPO	-	250
NQ_i	-	1, 3
$NRTS_i$	-	.2, .9
NRU	-	15
NS_c	-	226
NS_o	-	175
NSE	-	2
NTOT	-	401
NY	-	20
OH	-	29.2
$PBMS_k$@	-	.05
RLS_i	-	6, 7
RLS_1	-	2
RMS_i	-	100, 400
RMS_1	-	30
RRS_i	-	1.5, 1
RST_m	-	RSTC for CONUS, RSTO for overseas if under warranty CRSC for CONUS, CRSO for overseas
RSTC	-	384
RSTO	-	538
RTS_i	-	.7, 0 (1-$NRTS_i$ - $COND_i$)
SBMC	-	21.11
SBR	-	60.19
SCP@	-	3 (This value was arbitrarily chosen to allow calculations to be performed.)
SDC2	-	6.35
SDM	-	10.00

SDMC	- 6.35
SDR	- 41.62
SDR2	- 41.62
SID	- .0128
SIE	- 1299.00
SIM	- 216.00
SIN	- 41,516.00
SPSC	- 2.83
SPSO	- 4.88
TAT	- 168
UFP_i	- .1, .1
W	- 31, 1.3
WP	- 4
WPR	- 912

AD-A174 502 TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG AP..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. J E BOTKIN 2/2

UNCLASSIFIED SEP 86 AFIT/GSM/LSQ/86S-3 F/G 5/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Appendix E. Listing of CERs in Numerical Order

Note: The equations in this appendix are listed in numerical order by their C_{ik} designators, their equation number from the text is included for reference in ( ) at the right side.

$$C_{1k} = \frac{NAC_k}{NTOT} \times \left(\sum_{i \in I_1} NCS_i \times CRU_i \right) + \delta(k = WP+1) \times \sum_{j=1}^{k} \frac{NAC_j}{NTOT} \times \left(\sum_{i \in I_s} NCS_i \times CRU_i \right) + \delta(k > WP+1) \times \left(\frac{NAC_k}{NTOT} \right) \times \sum_{i \in I_s} NCS_i \times CRU_i \qquad (1)$$

$$C_{2k} = \left(RLS_1 \times \left[\sum_{m=1}^{12} \frac{NCUM_{km} \times NQ_1 \times OH \times RTS_1}{G_{km} \times MTBF_1} \right] + \sum_{i \in I_1} ENR_{ik} \times RRS_i \right) \times \left(\frac{24309}{12 \times 144 \times .75} \right) \qquad (2)$$

$$C_{3k} = \left(\sum_i \delta(LV_i = 1) \times ENR_{ik} \times FVS_i + \delta(LREM_i = 1) \times ENR_{ik} \times RRS_i \right) \times \left(\frac{24309}{12 \times 144 \times .75} \right) \qquad (3)$$

$$C_{4k} = \delta(k > WP) \times \sum_i ENR_{ik} \Big(\delta(k \leq ISP) \Big(\delta(LV_i = 2) \times FVS_i \times SDR + (1 - UFP_i) \times NRTS_i \times \left(RLS_i \times SDR + SDMC + RMS_i \right) + \delta(LREM_i = 2) \times RRS_i \times (SDR + SDMC) \Big) + \delta(k > ISP) \Big(\delta(LV_i = 2) \times FVS_i \times SDR2 + (1 - UFP_i) \times NRTS_i \times \left(RLS_i \times SDR2 + SDC2 + RMS_i \right) + \delta(LREM_i = 2) \times RRS_i \times (SDR2 + SDC2) \Big) \Big) \qquad (4)$$

$$C_{5k} = (k > WP) \times NI \times SIM \tag{5}$$

$$C_{6k} = (NPB + NPO) \times SDM + (k > WP) \times NPD \times SDM \tag{6}$$

$$C_{7k} = \sum_i \delta(LREM_i \leq 1) \times CPS_i \times ENR_{ik} \times (1-UFP) \times \Bigg(2 \times NRTS_i + COND_i + \delta(LR_i = 2) \times 2 \times RTS_i + \delta(LV_i = 2) \times 2 \times \frac{UFP_i}{1 - UFP_i} + \delta(LV_i = 2) \times COND_i \Bigg) \tag{7}$$

$$C_{8k} = \sum_{j=1}^{NSE} NREQ_{jk} \times CSE_j \times COM_j \tag{8}$$

$$C_{9k} = 152 \times SDR \times (MM)_{AM} \tag{21}$$

$$C_{10k} = NMOD_{jk} \times HMOD_{jk} \times SDR \times (k \leq WP) + NMOD_{jk} \times HMOD_{jk} \times SDR2 \times (k > WP) \tag{22}$$

$$C_{11k} = CMOD_{jk} \times NMOD_{jk} \tag{23}$$

$$C_{12k} = (SCP > 0) \times \frac{NAC_k}{NTOT} \times CSC \tag{24}$$

$$C_{13k} = .120 \times (3200+7767) \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \tag{25}$$

where

$$\text{Maintenance Man Hours} = \left(RLS_1 \times \sum_{m=1}^{12} \frac{NCUM_{km}\ NQ_1\ OH\ RTS_1}{G_{km}\ MTBF_1} \right) + \left(\sum_{i \in I_1} ENR_{ik} \times RRS_i \right) + \sum_i \Bigg(\delta(LV_i = 1) \times ENR_{ik} \times FVS_i + \delta(LREM = 1) \times ENR_{ik} \times RRS_i \Bigg) + \Bigg(\delta(k > WP) \times \sum_i ENR_{ik} \times \Bigg(\delta(k \leq ISP)\ \delta(LVi = 2) \times FVSi + (1-UFPi) \times NRTS_i \times RLS_i +$$

$$\delta(LREM_i=2) \times RRS_i + \delta(k > ISP) \times \delta(LV_i=2) \times FVS_i + (1-UFP_i) \times NRTS_i \times RLS_i + \delta(LREM_i=2) \times RRS_i \Big)\Big)$$

$$C_{14k} = 451 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \qquad (26)$$

$$C_{15k} = 5030 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \qquad (27)$$

$$C_{16k} = 758 \times \frac{\text{Maintenance Man Hours}}{144 \times 12 \times .75} \qquad (28)$$

$$C_{17k} = PBMS_k \sum_{i=1}^{16} C_{ik} \qquad (29)$$

$$C_{18k} = NAC_k \times ACS \qquad (9)$$

$$C_{19k} = \frac{NAC_k}{NTOT} \times \sum_{i \in I_1} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right) + $$

$$+ \delta(k=WP+1) \times \sum_{j=1}^{k} \frac{NAC_j}{NTOT} \sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} \right.$$

$$\left. + NRSD_i \times CRU_i \right) + \delta(k > WP+1) \times \frac{NAC_k}{NTOT}$$

$$\sum_{i \in I_s} \left(\sum_{m=1}^{NBASE} NRSB_{im} + NRSD_i \times CRU_i \right) \qquad (10)$$

$$C_{20k} = \delta(k \geq ISP) \frac{NAC_k}{NTOT} \times \sum_{j \in J_b} \sum_{m=1}^{ISITE} CSE_j \times n_{jm}$$

$$+ \delta(k=WP+1) \times \left[\sum_{i=1}^{k} \frac{NAC_i}{NTOT}\right] \times \left[\sum_{j \in J_d} n_j \times CSE_j\right]$$

$$+ \delta(k > WP+1) \times \left[\frac{NAC_k}{NTOT}\right] \times \left[\sum_{j \in J_d} n_j \times CSEj\right] \qquad (11)$$

$$C_{21k} = NAC_k \times SIN \qquad (12)$$

$$C_{22k} = \delta(WP > 0) \times \frac{NAC_k}{NTOT} \times WPR \qquad (13)$$

$$C_{23k} = \delta(k=1) \times BTC + \delta(k=WP+1) \times DTC \qquad (14)$$

$$C_{24k} = \delta(k=1) \times (DCB + DCO) + \delta(k=WP+1) \times DCD \qquad (15)$$

$$C_{25k} = \delta(k=WP+1) \times NI \times SIE \qquad (16)$$

$$C_{26k} = \delta(k=1) \times SID \times (2 \times NPB \times NBASE + NTOT \times NPO)$$

$$\delta(k=WP+1) \times 5 \times NPD \times SID \qquad (17)$$

$$C_{27k} = \sum_{i=1}^{17} C_{ik} \qquad (18)$$

$$C_{28k} = \sum_{i=18}^{26} C_{ik} \qquad (19)$$

$$C_{29k} = C_{27k} + C_{28k} \qquad (20)$$

Appendix F. Sample Numerical Calculations Year Ten

Note: These calculations involve only one LRU and one SRU of the F-111 DFCS. The inclusion of all LRUs and SRUs would be confusing and too lengthy for incorporation in this thesis.

Unit Mission Personnel

Unit mission personnel costs consist of C_{2k} and C_{3k}. C_{2k} and C_{3k} require an intermediate calculation of ENR_{ik}. Since the data set is being restricted to one LRU and one SRU, the values are labeled ENR_{2k}, and ENR_{3k} respectively.

$$ENR_{2k} = \frac{12 \times 401 \times 29.2 \times 1}{(1-.1) \times 1 \times 1750} = 90 \quad \text{(This value rounded up)}$$

$$ENR_{3k} = \frac{12 \times 401 \times 29.2 \times 3}{(1-.1) \times 1 \times 22750} = 21 \quad \text{(This value rounded up)}$$

$$C_{2k} = \frac{12 \quad 401 \times 1 \; 29.2 \times .9}{1 \times 854} + 90 \times 6 \times \frac{24309}{12 \times 144 \times .75}$$

$$= 15{,}683.77$$

$$C_{3k} = (1 \times 90 \times .5 + 0 \times 90 \times 1.5) \times \frac{24309}{12 \times 144 \times .75}$$

$$+ (0 \times 21 \times 2) + (1 \times 21 \times 1) \times \frac{24309}{12 \times 144 \times .75} = 1237.96$$

Unit Level Consumption

Unit level consumption cost consists of C_{17k}. The tenth year cost is a percentage of the sum of all the other O&S cost elements for the tenth year.

$$C_{17k} = .05 \times \sum_{i=1}^{16} C_{ik} = .05 \times 803{,}800.93 = 40{,}190.05$$

Depot Level Maintenance

Depot level maintenance costs consist of C_{4k}, C_{8k}, C_{9k}, C_{10k}, and C_{12k}.

$$C_{4k} = 1 \times 90 \times (0 \times 0 \times .5 \times 41.62 + .9 \times .2 \times (6 \times (41.62+6.35) + 100) + 0 \times 1.5 \times (41.62+6.35) + 1 \times 0 \times .5 \times 41.62 + .9 \times .2 \times 6 \times (41.62+6.35) + 100 + 0 \times 1.5 \times (41.62+6.35))$$
$$+ \quad 1 \times 21 \times (0 \times 1 \times 2 \times 41.62 + .9 \times .9 \times (7 \times (41.62+6.35) + 400) + 0 \times 1 \times (41.62+6.35) + 1 \times 1 \times 2 \times 41.62 + .9 \times 7 \times (41.62+6.35) + 400 + 0 \times 1 \times (41.62+6.35)) = 12{,}565.37 + 1341.44 = 13{,}906.81$$

$C_{8k} = 6 \times 657{,}571 \times .08 = 315{,}634.08$ (In this calculation only one piece of the support equipment is employed, the full F-111 database contains more support equipment. Additionally, it is assumed that only one piece of equipment is required at each station.)

$$C_{9k} = 152 \times 41.62 \times (MM)_{AM}$$

$$(MM)_{AM} = EAF_M \times (MM)_{NOM} \times ACT$$
$$= 1.1 \times 1 \times 2.8 \times (50)^{1.26} \times .1 = 42.584$$

$$C_{9k} = 152 \times 41.62 \times 42.584 = 269{,}400.62$$

$$C_{10k} = 50 \times 5 \times 41.62 \times 0 + 50 \times 5 \times 41.62 \times 1 = 10{,}405$$

$$C_{12k} = 1 \times \frac{0}{401} \times 2{,}000{,}000 = 0$$

Personnel Acquisition and Training

The personnel acquisition and training costs in year ten are generated by C_{13k}. The value of maintenance man hours (MMH) will be determined first.

$$MMH = \frac{2 \times 12 \times 401 \times 1 \times 29.2 \times .9}{1 \times 854} + 90 \times 1.5 + 1 \times 90 \times .5$$
$$+ 0 \times 90 \times 1.5 + 0 \times 21 \times 2 + 1 \times 21 \times 1 + 1 \times 90$$
$$\times (0 \times 0 \times .5 + .9 \times .2 \times 6 + 0 \times 1.5 + 1 \times 0 \times .5$$
$$+ .9 \times .2 \times 6 + 0 \times 1.5)$$
$$+ \quad 0 \times 21 \times 2 + 1 \times 21 \times 1 + 1 \times 21 \times (0 \times 1 \times 2 + .9 \times .9$$
$$\times 7 + 0 \times 1 + 1 \times 1 \times 2 + .9 \times .9 \times 7 + 0 \times 1) = 938.7$$

$$C_{13k} = .120 \times (3200+7767) \times \frac{MMH}{144 \times 12 \times .75}$$
$$= 1358.32$$

Sustaining Investment

The sustaining investment costs in year ten are computed by summing C_{1k} and C_{11k}. The value of NCS_i for calculating C_{1k} was obtained from output generated by the LCC-2 software program.

$$C_{1k} = \frac{0}{401} \times (129 \times 97{,}652) + 0 \times (1) \times 30 \times 4439 + 1 \times \frac{0}{401}$$
$$= 0$$

C_{11k}= 3,000 x 50 = 150,000

Indirect Personnel Support

The indirect personnel support costs consist of the sum of C_{14k}, C_{15k}, and C_{16k}. These CERs all have the value of adjusted maintenance man hours in common, which is:

$$\frac{\text{MMH}}{144 \times 12 \times .75} = .1924$$

C_{14k}= 451 x .1924 = 86.79

C_{15k}= 5030 x .1924 = 967.96

C_{16k}= 758 x .1924 = 145.87

Depot Non-Maintenance

The depot non-maintenance costs are given by C_{5k}, C_{6k}, and C_{7k}. Prior to computing C_{7k} the intermediate value of CPS_i must be obtained for the LRU and SRU (CPS_2 and CPS_3).

C_{5k}= 1 x 75 x 216 = 16,200

C_{6k}= (10+250) x 10 + 1 x 225 x 10 = 4850

$$CPS_2 = 31 \times \frac{226}{401} \times 2.83 + \frac{175}{401} \times 4.88 = 115.46$$

$$CPS_3 = 1.3 \times \frac{226}{401} \times 2.83 + \frac{175}{401} \times 4.88 = 4.84$$

$$C_{7K} = 1 \times 115.46 \times 90 \times .9 \times 2 \times .2 + .1 + (0 \times 2 \times .7)$$

$$+ (0 \times 2 \times \frac{.9}{.1}) + 0 \times 1$$

$$+ 1 \times 4.84 \times 21 \times .9 \times 2 \times .9 + .1 + (1 \times 2 \times 0) + 1 \times 2$$

$$\frac{.9}{.1} + 1 \times .1 = 3923.75$$

Total O&S Costs

$$C_{27k} = 0 + 15{,}683.77 + 1{,}237.96 + 13{,}906.81 + 16{,}200 + 4{,}850$$

$$+ 3923.75 + 315{,}634.08 + 269{,}400.62 + 10{,}405$$

$$+ 150{,}000 + 0 + 1358.32 + 86.79 + 967.96 + 145.87$$

$$+ 40{,}190.05 = 843{,}990.98$$

Bibliography

1. Barton, Richard F. A Primer on Simulation and Gaming. Englewood Cliffs NJ: Prentice-Hall Inc., (1970).

2. Blanchard, Benjamin S. Design and Manage to Life Cycle Cost. Portland OR: M/A Press, (1978).

3. Boden, William H. "Designing for Life Cycle Cost," Defense Management Journal, 12: 29-37 (January 1976).

4. Boehm, Barry W. Software Engineering Economics. Englewood Cliffs NJ: Prentice-Hall Inc., (1981).

5. Byrd, Jack Jr. and Ted L. Moore. Decision Models for Management. New York NY: McGraw-Hill Book Co., (1982).

6. Cira, Capt. A. T. and Capt. Kenneth R. Jennings. Life Cycle Costing: A Working Level Approach. MS thesis, LSSR 37-81. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH., September 1979 (AD-A076 981).

7. Collins, Lt Dwight E. "Models A Key to Air Force Life Cycle Cost Implementation," Defense Management Journal, 12: 54-59 (January 1976).

8. Doane, Robert B. "The Evolving Nature of the C3 Systems Acquisition Process," Concepts, Journal of Defense Systems Acquisition Management, 5: 177-190 (Autumn 1982).

9. Department of Defense. Design to Cost. DOD Directive 4245.3. Washington DC: Government Printing Office, (6 April 1983).

10. Department of Defense. Major Systems Acquisitions. DOD Directive 5000.1. Washington DC: Government Printing Office, (12 March 1986).

11. Department of Defense. OSD Cost Analysis Improvement Group (PA&E). DOD Directive 5000.4. Washington DC: Government Printing Office, (30 October 1980).

12. Department of the Air Force. Life Cycle Cost Management Program. AFR 800-11. HQ USAF, Washington DC, (27 January 1984).

13. Department of the Air Force. Memorandum from Cost Analysis Division. Subject: Cost Element Structures for Operating and Support Costs. Washington DC, (27 April 1983).

14. Department of the Air Force. US Air Force Cost and Planning Factors. AF Regulation 173-13. Washington DC: Government Printing Office, (1 February 1985).

15. Earles, Mary Eddins. Factors, Formulas, and Structures for Life Cycle Costing. Concord MA: Eddins-Earles, (1981).

16. Edmund, Maj. Robert. Chief Life Cycle Cost Division. Personal and telephone interviews. Aeronautical Systems Division (ASD/ALTB), Wright-Patterson AFB OH, 15 August 1985 to 6 February 1986.

17. Farnell, Capt Fredrick C. A Further Examination of Operational Availibility in Life Cycle Cost Models. MS thesis, GLM/LSM/84S-19. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1984 (AD-A146 935).

18. Ferens, Daniel V. and Robert L. Harris. "Avionics Computer Software Operational and Support Cost Estimation", IEEE 1979 National Aerospace and Electronics Conference, 1: 296-300 (May 1979).

19. Fifer, Lt. Larry. Logistics Modeling and Resource Analyst. Personal and telephone interviews. Air Force Aeronautical Systems Division (ASD/ALTB), Wright-Patterson AFB OH, (15 August 1985 to 29 August 1986).

20. Ganley, Michael. "Reagan's Order to Implement Packard Reforms Catches DOD by Surprise," Armed Forces Journal. 123: 15 (May 1986).

21. Gansler, Jacques S., and George W. Sutherland. "A Design to Cost Overview," Defense Management Journal, 10: 2-7 (September 1974).

22. Gates, Robert and Michael J. Abraham. Program LCC Documentation Version 2. Contract F33657-75-C-0674. The Analytical Sciences Corporation, Reading MA, (28 April 1976).

23. Hardy, Chester A. "The F-16: A Successful Effort to Contain Logistic Support Costs,"Defense Management Journal, 20: 8-15 (January-March 1984).

24. Huff, John. Operations Research Analyst. Personal interview. Air Force Acquisition Logistics Center (AFALC/LSS), Wright-Patterson AFB OH, (6 February 1986).

25. Kankey, Roland D. "Precepts for Life Cycle Cost Management," Air Force Journal of Logistics, 6: 28-30 (Winter 1982).

26. Krisch, Marc J. "Cost Estimating Getting Rid of the Guesswork," International Defense Review, 17: 1527-1529 (October 1984).

27. Long, Maj. John A. Life Cycle Costing in a Dynamic Environment. Doctoral Dissertation. The Ohio State University, Columbus OH, (1983).

28. Marks, Kenneth E. et al. An Appraisal of Models Used in Life Cycle Cost Estimating of USAF Aircraft Systems. Rand No. R-2287-AF. The Rand Corp., Santa Monica CA, October 1978 (AD-A064333).

29. May, Maj. Thomas E. Operating and Support Cost Estimating, A Primer. Life Cost Management Division, Directorate of Cost Analysis, Comptroller, Aeronautical Systems Division, Wright-Patterson AFB OH, May 1982.

30. Office of Secretary of Defense. Cost Analysis Improvement Group, Aircraft Operating and Support Cost Guide. Washington DC: 15 April 1980.

31. Pitterle, Capt. Elise Killian. An Identification of Operating and Support Cost Drivers for Command, Control,Communications, and Intelligence Systems. MS thesis, GSM/LSY/85S-26. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, (September 1985).

32. Powers, Capt. Clarke W. and Thomas J. Recktenwalt. Air Force Acquisition Logistics Division, Its Creation and Role. MS Thesis, AFIT-LSSR-32-78B. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1978 (AD-A061357).

33. Recktenwalt, Thomas J. "The Air Force Visibility and Management of Operating and Support Costs; A Practical Approach to O&S Costing: Staff Report." Office of VAMOSC, HQ AFLC, Wright-Patterson AFB OH, September 1982 (AD-125 986).

34. Shannon, Robert E. Systems Simulation the Art and Science. Englewood Cliffs NJ, Prentice-Hall, Inc., (1975).

35. Shorey, Russell R. Managing Downstream Weapons Acquisition Costs," Defense Management Journal, 12: 10-18 (January 1976).

36. Sims, Capt Sherry. "Life Cycle Cost Cost Management," Air Force Comptroller, 12: 12-15 (July 1978).

37. Tihansky, Dennis P. "Confidence Assessment of Military Airframe Cost Predictions," Journal of the Operations Research Society, 24: 26-43 (January-February 1976).

38. Vollmann, Thomas E. Operations Management. Reading MA, Addison-Wesley Publishing Co., (1973).

39. Wasley, Austin. Budget Analyst, Telephone interview. AF/ACBMC, Pentagon, Washington DC, (5 June 1986).

VITA

Captain James E. Botkin was born on 8 April 1956 in Springfield, Ohio. He graduated from high school in Dayton, Ohio, in 1974 and attended the University of Cincinnati from which he received the degree of Bachelor of Science in Electrical Engineering in June 1980. Upon graduation, he received a commission in the USAF through the Reserve Officers Training Corps program. He was called to active duty in October 1980. He completed the Communication Electronics Officers School at Keesler AFB, Mississippi in April 1981. He then served as a telecommunications systems analyst at Headquarters Foreign Technology Division, Air Force Systems Command, Wright-Patterson AFB, Ohio until entering the School of Systems and Logistics, Air Force Institute of Technology, in May 1985.

Permanent address: 5424 Plainfield Rd.
Dayton, Ohio 45432

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GSM/LSQ/86S-3	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL (If applicable) AFIT/LSQ	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, OH 45433-6583	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19	
12. PERSONAL AUTHOR(S) James E. Botkin Captain, USAF	

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1986 September	111

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Life Cycle Costs, Accounting, Cost Models, Cost Analysis, Aircraft
05	01		
14	01		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: TRANSLATION OF THE LCC-2 LIFE CYCLE COST MODEL TO COMPLY WITH THE CAIG APPROVED COST ELEMENT STRUCTURE

Thesis Chairman: John A. Long, Lieutenant Colonel, USAF
Assistant Professor Department of Quantitative Management

Approved for public release: IAW AFR 190-1.
LYNN E. WOLAVER 29 Sept 86
Dean for Research and Professional Development
Air Force Institute of Technology (AFC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL John A. Long Lt Col, USAF	22b. TELEPHONE NUMBER (Include Area Code) (513)-255-6280 22c. OFFICE SYMBOL AFIT/LSQ

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE. UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

This modification of the LCC-2 life cycle cost model cost element structure has separated acquisition costs from O&S costs, and by then adding missing ownership cost elements, has transformed the model into compliance with the Secretary of Defense Cost Analysis Improvement Group's (OSD/CAIG) standard cost element structure for aircraft systems. The modification of the software code to implement the modified cost element structure will once again allow the extensive use of the model for life cycle cost analysis.

The modification was accomplished through a comparison of the LCC-2 cost elements with the CAIG approved cost elements and modifying the LCC-2 cost estimating relationships, which produce the cost elements, so as to generate the approved cost elements. Additionally, new cost estimating relationships were devised to supply output for cost elements not previously addressed by the LCC-2 model.

Although the model was originally developed for use in the life cycle costing of avionics systems, the model should be applicable to other aircraft subsystems as well.

END

12-86

DTIC